Spring 4-2021

Occurrence and Potential Transformation Pathways of Nitrogen Species in the Intermediate Vadose Zone

Jordan Shields
University of Nebraska-Lincoln, jordan.shields90@huskers.unl.edu

Occurrence and Potential Transformation Pathways of Nitrogen Species in the Intermediate Vadose Zone

by

Jordan Shields

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professor Daniel Snow

Lincoln, Nebraska

May 2021

Occurrence and Potential Transformation Pathways of Nitrogen Species in the Intermediate Vadose Zone

Jordan D. Shields, M.S.

University of Nebraska, 2021

Advisor: Daniel Snow

Nebraska is a large agricultural producing state with a heavy reliance on groundwater resources and nitrogen fertilizer application to maintain output. Poor management, such as excessive fertilizer application, improper timing, and over irrigation can lead to contamination of groundwater. Nitrate is the leading groundwater contaminant in Nebraska and chronic consumption at medium to high concentrations leads to adverse health effects. Nitrate, a highly soluble anion, is present in the root zone in numerous forms and undergoes biogeochemical transformations before being leached through the profile. In order to predict the timing and quantity of nitrate contamination in groundwater, researchers study the vadose zone, which is the soil and sediments from the land surface to the groundwater. The vadose zone acts as a storage compartment and transforms chemicals, such as nitrate, and acts as a filter for percolating water. A majority of research focuses on nitrate-nitrogen in the vadose zone, but an investigation of nitrogen storage in the vadose zone in the Central Platte region of Nebraska measured significant concentrations of ammonium, a cation expected to bind to clay particles in surface soils. In the Central Platte, overall, average nitrate storage in the vadose zone

decreased by 10% in the past 30 years, with a large drop in surface loading, hinting that management practices have been effective. It was hypothesized that ammonium is a product of dissimilatory nitrate reduction to ammonium (DNRA), a biotic pathway that converts nitrate to ammonium. Selected samples were further analyzed to determine total Kjeldahl nitrogen (TKN), hot water extractable organic carbon (HWEOC), total organic carbon (TOC), and δ^{13}C-OC to help evaluate potential chemical and microbial transformations of nitrogen to ammonium in the vadose zone. The hypothesis was rejected for site DH-32, where a spike of ammonium (3.56 μg/g), a drop in pH (5.92), slight increase in nitrate concentration (0.99 μg/g), and δ^{13}C-OC enrichment (-22.2 ‰) hint at an alternate process. The hypothesis was supported for site DH-36, where a spike in ammonium concentration (8.46 μg/g), drop in nitrate concentration (0.26 μg/, a negative gradient in pH (6.83), and no δ^{13}C-OC enrichment (-27.4 ‰) hint at DNRA.

Acknowledgements

First, I would like to thank the Central Platte Natural Resource District and the Nebraska Environmental Trust for providing the funding for my graduate research assistantship to support the vadose zone study in the Central Platte NRD. The University of Nebraska provided an invaluable education with many irreplaceable connections to people and experiences.

I would like to thank my advisor, Dr. Daniel Snow for his great deal of knowledge and support in the past four and a half years in the Nebraska Water Sciences Laboratory. I learned a lot about laboratory methods, field methods, research, and interaction with fellow scientists and multi-disciplinary teams. His guidance and support helped me develop a tremendous amount academically, as a scientist, and a person. His support helped me gain numerous experiences, from conferences to field trips to international research experience. He has helped provide me with the tools that I will need to continue my success as I continue the journey through my career as a scientist.

I would also like to thank my committee members: Dr. Michael Kaiser and Dr. Dan Miller. Their knowledge and expertise in their subjects helped contribute to the success of my research and this thesis. I was always very impressed and thoroughly enjoyed the conversations that took place during my thesis committee meetings. They helped discuss initial findings, determine what experiments would be conducted, and helped with data interpretation. Without their help and guidance my thesis would not be up to its current level.

I would like to give thanks to Dr. Chittaranjan Ray for his support and guidance. He always had good advice and input on my research and provided the opportunity to conduct international research in the Czech Republic. I would also like to thank Dr. Arindam Malakar, my unofficial committee member. Throughout my tenure as a M.S. student, we had countless conversations about science and our goals, usually in the car between Lincoln and Scottsbluff or over lunch. He helped me develop my thesis topic and recruited me to help with other projects. He taught me a lot and helped me experience scientific methods that expanded my understanding of the environment.

Thank you to Matt Marxsen and John Seamann for their seemingly endless help collecting cores, moving coolers, and letting me borrow pickup trucks as needed. They made the logistics a breeze. Thank you to Dan Clemente from the CPNRD, he picked the coring locations and gained permission from landowners for site access. Thank you to Craig Adams for helping train me in core processing and going out to collect soil cores. I would also like to thank all of my colleagues at the Nebraska Water Sciences Laboratory; they have always been very helpful and facilitated a laboratory environment that is conducive to completing work. It is always a pleasure working with you all.

Lastly, I would like to thank my parents. Their endless love, support, and encouragement throughout my life, and especially this chapter, have been imperative in maintaining direction and motivation. I would not have made it this far without their support. I would especially like to thank my fiancé, Kristi, for always being beside me and supporting me in my academic journey.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

CPNRD	Central Platte Natural Resource District
$\delta^{13}C$	Isotope ^{13}C
DDI	Distilled Deionized Water
DNRA	Dissimilatory Nitrate Reduction to Ammonium
DOM	Dissolved Organic Matter
EPA	Environmental Protection Agency
GWMA	Groundwater Management Area
HWEOC	Hot water extractable organic carbon
LFB	Laboratory Fortified Blank
LRB	Laboratory Reagent Blank
Ksat	Saturated Hydraulic Conductivity
M	Molar
Ma	‘Mega Annum’; millions of years
MCL	Maximum Contaminant Level
MSEA	Management Systems Evaluation Area
NO3-N	Nitrate as Nitrogen; specifically measures the amount of nitrogen in the nitrate ion in the sample
NH4-N	Ammonium as Nitrogen; specifically measures the amount of nitrogen in the ammonium ion in the sample
QA	Quality Assurance
SOM	Soil Organic Matter
TKN	Total Kjeldahl Nitrogen
TOC	Total Organic Carbon
WFPS	Water Filled Pore Space
g	Gram; measures mass
mg	Milligram (1,000 mg = 1 g); measures mass

µg	Microgram (1,000,000 = 1 g); measures mass
L	Liter; measures volume
mL	Milliliter (1,000 mL = 1 L); measures volume
g/cm^3	Grams per cubic centimeter (1 g/cm^3 = 1 g/mL); measures mass over volume, or density
mg/L	Milligrams per liter (1,000,000 mg/L = 1 g/cm3 = 1 g/mL); measures mass over volume, or density
µg/g (ppm)	Microgram per gram and parts per million; measures mass over mass, also known as mass percent (1 µg/g = 1 ppm)
lbs-N/Acre	Pounds of nitrogen in the vadose zone per acre
%	Percentage (per 100)
‰	Percentage (per 1000)

Occurrence and Potential Transformation Pathways of Nitrogen Species in the Intermediate Vadose Zone

1. Introduction

Clean drinking water is necessary to sustain a healthy population (Pennino et al., 2017). Nitrate is the most common contaminant affecting aquifers worldwide (Adelman et al., 1985; Exner et al., 2014; Gurdak & Qi, 2012; Rees et al., 1995; Schaider et al., 2019) and nonpoint source nitrogen contamination of groundwater has been well documented for years (Bobier et al., 1993; Exner et al., 2014). Contamination of groundwater by nitrate is a concern to both human and livestock health (Exner et al., 2014; Gurdak & Qi, 2012; Putz et al., 2018; Schaider et al., 2019). In 1972 under the Safe Drinking Water Act, studies were conducted and a maximum contaminant level (MCL) for nitrate in groundwater of 10 mg/L was created to help protect infants from methemoglobinemia (Adelman et al., 1985; Di & Cameron, 2002; Exner et al., 2014; Gurdak & Qi, 2012; Temkin et al., 2019).

Current research on human health effects from nitrate contamination has correlated chronic nitrate exposure with cancer (bladder, thyroid, colon, and kidney) and birth defects (low birth weight, preterm birth) (Gurdak & Qi, 2012; Schaider et al., 2019). Some of these studies have gone further, questioning the MCL limit set by the Environmental Protection Agency (EPA) as too high. Large epidemiological studies have seen statistically significant increases in some of these cancer risks at chronic exposure to limits ranging between 0.7-2.0 mg/L (Temkin et al., 2019). As a result of indirect costs, such as healthcare, loss of productivity, and death, nitrate related contamination leads to an annual loss of somewhere between $2.3-$12.6 billion (Temkin et al., 2019). Nitrogen management is important for human, livestock, economic, and environmental health.

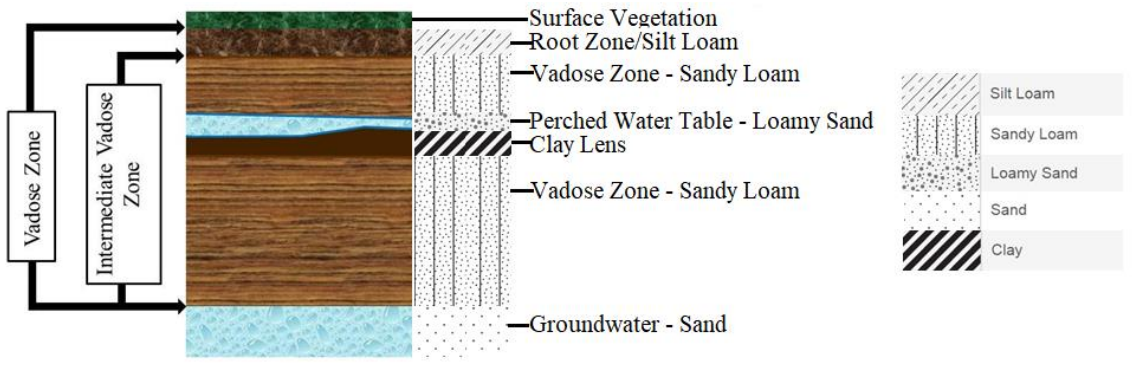


Figure 1. An example scheme of the vadose zone across a range of substrate textures, differentiating the full vadose zone from the intermediate and including a potential perched water table atop of a restrictive clay lens.

Studies have shown that increasing nitrate-N concentrations in groundwater is linked directly to loading at the surface and transport from the vadose zone (Exner et al., 2014; Liu et al., 2013; Xin et al., 2019). In order to reach groundwater, nitrate must first pass through the vadose zone (Figure 1). Fertilizers applied at the surface have the potential to be leached through the root zone, which is the uppermost layer of the vadose one (Hergert & Shapiro, 2015). Nitrogen in the root zone interacts with plants, soil minerals, and microbial communities (Di & Cameron, 2002). Once it passes through the root zone, it reaches the intermediate vadose zone, where it continues to leach towards the groundwater. Researchers have studied the vadose zone in order to get an estimate on when these contamination events will occur to help warn private well users when they will need to either treat their wells or find an alternate source of potable water.

Water content is a leading factor in nitrogen dynamics of soil (Mekala & Nambi, 2017). Water affects permeability, transport, microbial activity, and form that nitrogen takes in the vadose zone (Mekala & Nambi, 2017). Irrigation application, amounts and timing dictates if excess water will flush nitrate from the root zone and into the vadose zone. As the solute is transported towards the water table, it fills in pore space, switching the microsites from a potentially oxic to anoxic conditions, altering the redox state (Mekala & Nambi, 2017; Rubol et al., 2013). This switch in moisture content will drive a shift in microbial communities and nitrogen-N transformations within soil (Mekala & Nambi, 2017) because higher water filled pore space (WFPS) will result in a lower oxygen content (Cannavo et al., 2004).

Starting in 2016, a vadose zone study consisting of 27 cores was conducted in the Central Platte Natural Resource District (CPNRD) (Figure 2). That study was conducted to revisit previously cored locations from the mid-1990's to look at the changes in nitrate-N loading in the vadose zone from across the district and evaluate the management practices and regulations that were put in place. Nitrate-N in each sampled interval was graphically compared (Appendix 1), along with the total nitrate-N storage in the vadose zone (Table 3).

As it has been stated, nitrate-N is highly mobile and has major and minor health implications, so the historical study was focused on nitrate-N. In the 2016 study, ammonium-N was added to the analytes. Ammonium-N, which is a positively charged and mineralized form of nitrogen, has a lower mobility due to sorption to negatively charged clay particles (Böhlke et al., 2006). In the process of studying nitrate-N movement in the vadose zone in the CPNRD, sites with higher-than-expected concentrations of ammonium-N deeper in the vadose zone were discovered (Figure 3). Graphical results from this study can be found in Appendix 1.

At site DH-32, there are two depth intervals that show a higher concentration of ammonium than nitrate, with the more notable from 60-65', and the other 30-35'. At site DH-36, the zone of interest is from 35-40'. In this interval, there is an elevated ammonium concentration with a decreased nitrate concentration relative to samples collected above and below this zone. This thesis focuses on the interval of 60-65' at site DH-32 and the interval 35-40' at site DH-36. Due to established health effects of nitrate-N exposure, much of the research surrounding nitrogen content in the vadose zone has been focused on nitrate-N and largely ignores smaller pools, such as ammonium-N, which have been largely undescribed.

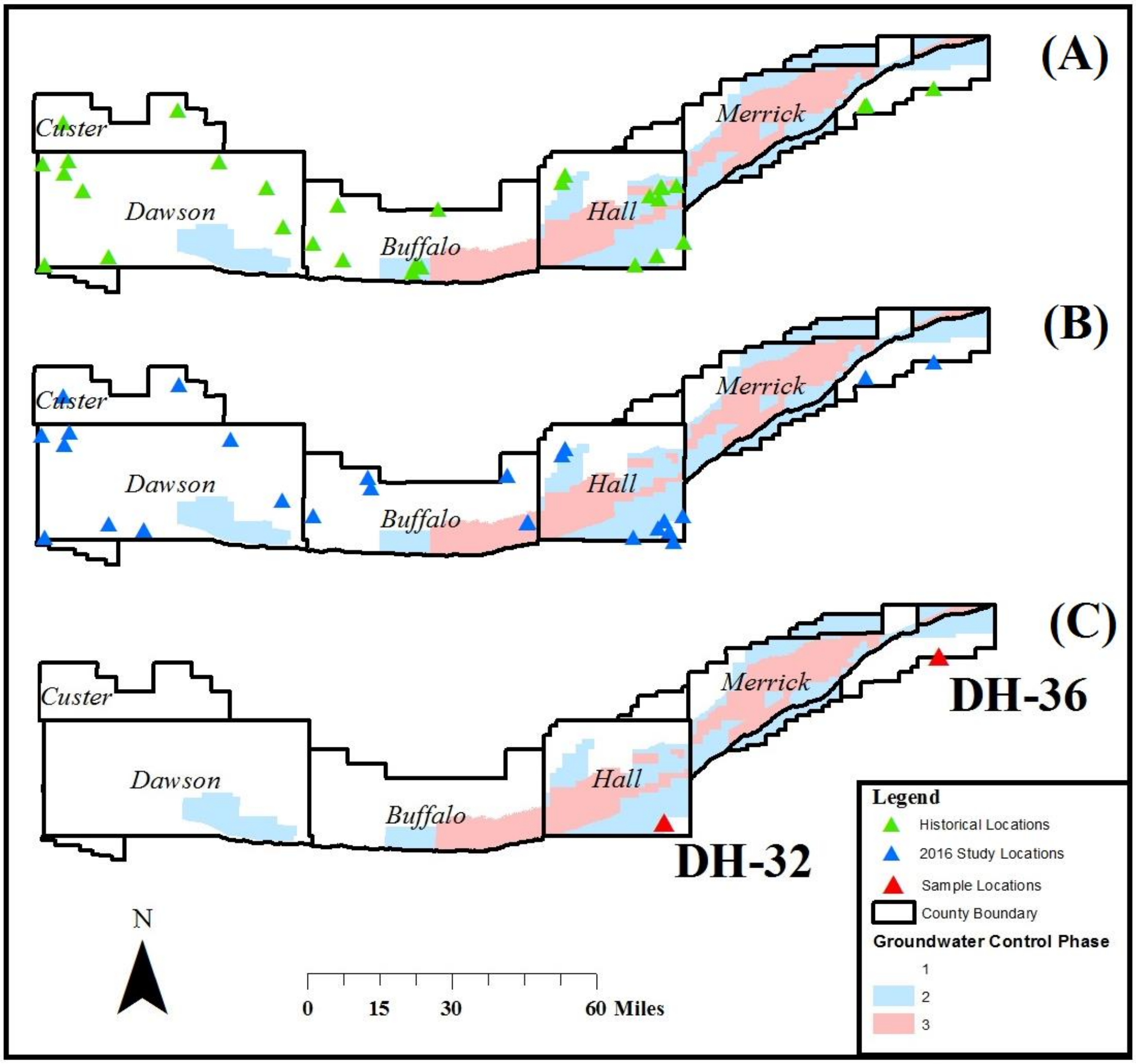


Figure 2. Vadose zone coring locations from the Central Platte Natural Resource District. (A) Historical Locations (B) 2016 Study Locations (C) Cores from this thesis.

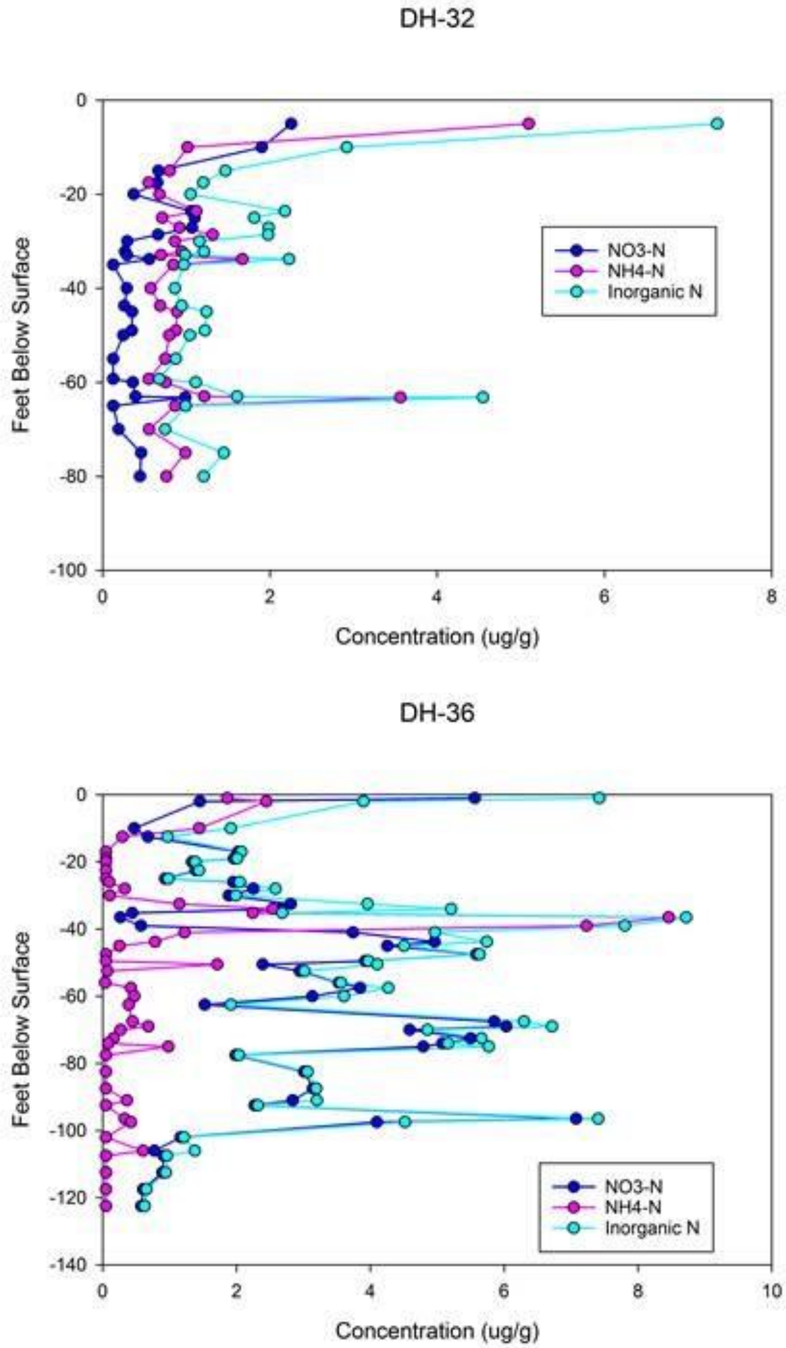


Figure 3. The two locations from the 2016 Central Platte Natural Resource District study that show elevated ammonium-N concentrations relative to nitrate-N concentrations that are the basis of this study.

In the present study, it is hypothesized that in agricultural production land that has been switched from gravity irrigation to pivot irrigation, the solute movement is slowed down, increasing the nitrogen residence times, which allows for more microbial processing to occur, converting nitrate to ammonium. The goal of this research is to address the elevated ammonium-N concentrations at sites DH-32 and DH-36 and establish whether related subsurface constituents can help identify the potential N source. Potential sources of this subsurface ammonium can be surface applied being transported to depth, mineralization of organic nitrogen from pathways such as dissimilatory nitrate reduction to ammonium (DRNA), abiotic reduction of nitrate to ammonium through iron catalyzation, or abiotic sulfur driven nitrate reduction to ammonium. Two intervals originating from two different cores were found to have ammonium-N concentrations higher than nitrate-N concentrations in the deep vadose zone at depths of 35-40’ and 60-65’. These cores were analyzed using laboratory methods for nitrate-N and ammonium-N extraction, Total Kjeldahl Nitrogen (TKN), total organic carbon (TOC), carbon-13 of organic carbon (δ13C-OC), and hot water extractable organic carbon (HWEOC) to identify potential sources of ammonium-N. Other physical and chemical properties were also analyzed to better understand the environment leading to ammonium accumulation within the deep vadose zone.

2. Central Platte Natural Resource District Vadose Zone Study

2.1 Project Summary

The purpose of this project was to sample and analyze spatial and temporal changes in vadose zone nitrogen storage and to compare results with previous data from the Central Platte Natural Resources District to relate to potential groundwater nitrate-N contamination. Individual cores were collected during and after the growing season between 2016 and 2019. Cores were collected, processed, analyzed, results graphed, and results interpreted within this thesis. The appendices consist of the graphs, tabulated results of laboratory analysis, tabulated results of selected sites analyzed for particle size distribution, and tabulated results of experiments from Chapter 3. Locations previously sampled in the 1990's allowed for comparison of changes in stored nitrogen.

Overall, the trends suggest that for locations previously sampled, the amount of vadose zone nitrogen storage in the upper layers of numerous fields appear to be slowly declining. Many locations have a reduce mass of stored NO_3-N in the top of the profile, which suggests to improved nitrogen and irrigation water management might have a positive effect. However, some locations indicate higher vadose NO_3-N concentrations near the surface suggesting recent leaching of excess fertilizer nitrate-N. Only five locations sampled had significantly higher vadose zone NO_3-N storage, where there was an increase of over 20%. There were also a few locations that had similar NO_3-N storage profiles relative to previous studies suggesting that movement is very slow or that surface loading has not changed. On average there was a 10% decrease in total nitrate-nitrogen in the vadose zone at all locations sampled.

Porewater NO_3-N, determined from sediment nitrate concentrations and gravimetric moisture content, are very high in many locations suggesting that historical nitrate-N leaching will continue to impact the local groundwater in areas with rapid movement. Overall, most locations suggest that changing management may eventually lead to a reduction in vadose zone nitrate-N and if so, would produce a long-term reduction in groundwater concentrations. Continued monitoring will help to ensure if this trend continues, ideally leading to reduced NO_3-N concentrations in both the vadose zone and groundwater across all sites.

2.2 Area of Study

Twenty-seven (27) locations (Figure 2) were identified by the CPNRD for subsequent sampling of the vadose zone. Cores were collected across the district from a variety of land use, topography, and soil type. All locations were selected by the CPNRD Water Resource Specialist, Dan Clement, and emphasized collection of cores from previous sample locations as well as evaluating the relationship to groundwater management phases. Coring locations are all under irrigated crop production, with 5 currently under gravity irrigation and the remaining 22 using pivot sprinkler irrigation (Table 4). Three cores were collected from quality control phase 2 land: DH-19, DH-20, and DH-32. Two cores were collected from quality phase 3 land within the same quarter section: MSEA-3 and MSEA-6 (Table 4).

The CPNRD spans the south-central region of Nebraska along the Platte River from its western boundary near Gothenburg to its eastern boundary near Osceola. The area directly adjacent to the Platte River consists of the Platte River Valley. This valley has very little relief and consists of high sand content soils in the top one meter of the profile (Figure 5). The water table is also very near the surface in certain areas. A consequence of this very flat and permeable land is that there is minimal runoff and a high chance of surface applied fertilizers to infiltrate into the groundwater (Exner et al., 2010). The region to the north of the Platte River Valley consists of loess deposit uplands that are shown to be between150-200' high (Diffendal & Smith, 1996). A majority of the land use is irrigated corn with a soybean rotation and pockets of rangeland bordering the Platte River (Meals et al., 2012).

During the Laramind orogeny, 75-35 Ma (millions of years ago), the Rocky Mountains to the west were uplifted, creating a source for water and sediments to be transported to the plains of Nebraska and form the basis of the South and North Platte Rivers. This uplift continued into the late Eocene epoch (Condon, 2005). As time progressed into the Oligocene epoch, volcanoes began to form west of the Rockies, stretching from Utah to Washington State. Uplift of the Rockies was interrupted and they began to become buried in their own debris and eolian volcanic materials from further west (Condon, 2005). Towards the end of the Oligocene epoch, uplift continued and the surface gradient began to increase away from the Rocky Mountains eastward. During this time period volcaniclastic sediments and rocks from the Rockies were deposited uninterrupted towards the plains, continuing into the Miocene epoch (Condon, 2005).

As the Miocene epoch began, the climate was cool and dry, a favorable condition for life with an abundance of diverse flora and fauna in the plains (Condon, 2005). During this epoch, the Ogallala formation was deposited from eastward drainage systems carrying gravel and sand. This sediment filled in previously eroded valleys from the

Oligocene epoch (Condon, 2005). After the Miocene, the Pliocene epoch had glaciation that covered the eastern third of what is now Nebraska (Condon, 2005; Peckenpaugh & Dugan, 1983). These ice sheets diverted the flow of rivers to the south and southeast, reducing the eroding power and sediment carrying capacity, resulting in aggredation of valleys (Peckenpaugh & Dugan, 1983). This led to the construction of alluvial plains, that became the basis of the Platte River channel in Nebraska (Peckenpaugh & Dugan, 1983).

As the ice sheets began to retreat and advance, there were several episodes of fluvial and eolian deposition. The deposit of coarse sand and mixed sand and gravel that was deposited underlies almost all of Hall County, Nebraska (NRCS, 2003). Much of this sand and gravel was weathered from igneous rocks, but also contain sediments from other types of rock (NRCS, 2003). The High Plains Aquifer in this area is primarily contained in Pleistocene sands and gravel with a gradient in thickness increasing from northwest to southeast (NRCS, 2003). The large textured material is generally below the upper fine textured sediments, with some sand sequences separated only by a thin layer of silt and clay (Figure 4) (Peckenpaugh & Dugan, 1983). The quaternary gravel, sand, silt, and clay deposits at the land surface are generally of fluvial origin, with some of the silt and clay being of eolian origin (Peckenpaugh & Dugan, 1983).

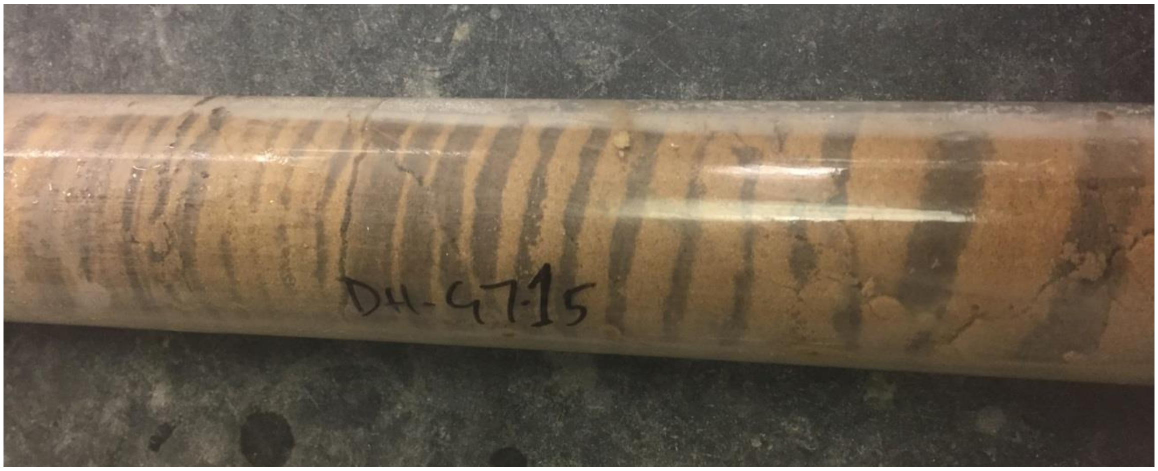


Figure 4. Core DH-47 from the CPNRD vadose zone study shows several thin clay lenses in between coarse textured sands in the intermittent vadose zone. DH-47 is less than two miles west of DH-32.

The vadose zone consists of these coarse-textured materials which allow for rapid percolation of solute above the primary aquifer (Exner et al., 2014; Schneider, 1990). Within the vadose zone, there are intermittent clay layers, which will restrict vertical solute transport and promote horizontal transport directly above the restrictive layer (Figure 4).

The Platte River runs west to east across the center of the district and groundwater flow generally runs parallel to the river. Many areas within the district lie within the Platte River valley and have a relatively shallow water table and sandy soils that allow for high water infiltration (Table 5). Soils in the eastern half of the district are characterized as sandy and well-drained with sand content as high as 90% (Figure 5). Because groundwater nitrate in these areas is also high, many of these areas typically are designated as groundwater quality control phase areas (Table 2) defined by average groundwater nitrate-N concentrations. Phase 2 and 3 management areas generally correspond to sand-rich well-drained soils prone to nitrate leaching.

Table 1. Site ID, coordinates, sample date, and rig type used for coring methods.

Site	Latitude	Longitude	Sampling Dates	Rig Type
DH-19-15	40.709581	-98.434800	3/29/16	CME
DH-20-15	40.774889	-98.285778	4/6/16	CME
DH-21-16	40.976983	-98.641439	11/16/16	CME
DH-22-2-16	41.188994	-97.737481	11/15/16	CME
DH-26-19	41.025300	-100.129444	12/11/19	CME
DH-28-17	40.749067	-100.01183	11/7/17	CME
DH-29-17	40.709528	-100.20247	11/6/17	CME
DH-30-17	40.773861	-99.397389	4/19/17	CME
DH-31-16	40.957383	-98.648400	11/21/16	CME
DH-32-15	40.738806	-98.360778	4/4/16	CME
DH-36-16	41.237247	-97.533028	11/15/16	CME
DH-37-18	40.822700	-99.491111	4/23/18	CME
DH-38-19	40.9883	-100.1438	4/23/18	CME
DH-39-19	41.016711	-100.2121	12/10/19	CME
DH-40-18	41.133700	-100.146389	4/23/18	CME
DH-41-18	41.169500	-99.799167	4/24/18	CME
DH-47-15	40.728472	-98.327528	3/30/16	CME
DH-48-15	40.698639	-98.316222	3/30/16	CME
DH-49-15	40.757639	-98.343361	3/31/16	CME
DH-50-20	40.7322	-99.9057	1/15/20	CME
MSEA-3-17	40.755617	-98.752772	11/14/17	GeoProbe
MSEA-6-17	40.753761	-98.755447	11/14/17	GeoProbe
Rosenau-17-19	40.732244	-99.905953	11/8/2017 & 12/12/19	CME
RS-1-20	41.0036	-99.6449	1/14/20	CME
RS6-17	40.858389	-99.221806	4/18/17	CME
RS8-17	40.896444	-98.815056	4/20/17	CME
RS9-17	40.889333	-99.231222	4/19/17	CME

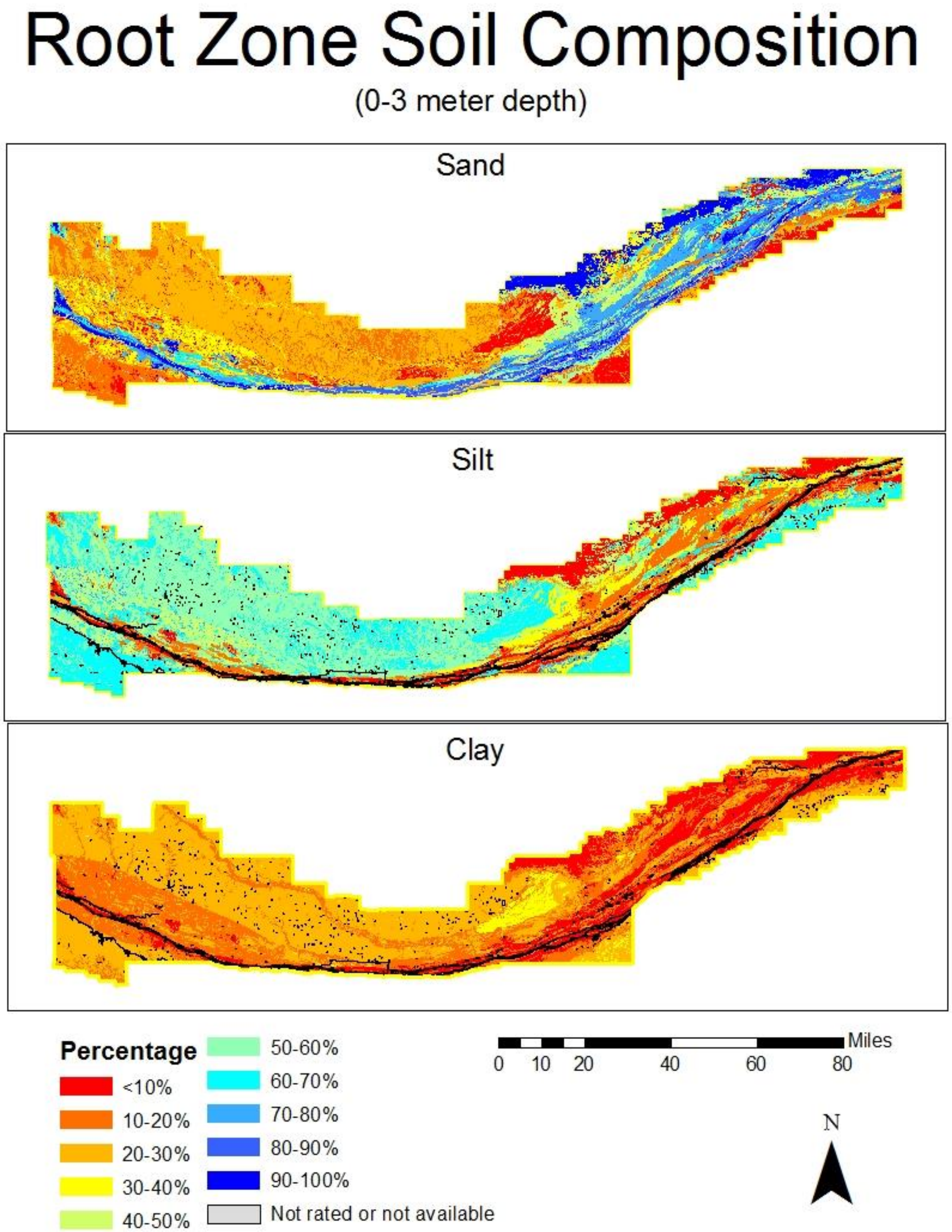


Figure 5. Root zone soil composition as a percentage from the United States Department of Agriculture Natural Resource Conservation Service Soil Survey Geographic Database.

Four groundwater quality control phase areas have been identified across the district: Phase 1, Phase 2, Phase 3, and Phase 4 (Table 4). In the Phase 1 zones, fall N applications on heavy soils are permitted after November 1 and producers can apply commercial N fertilizer on sandy soils after March 1. Phase 2 also allows application of commercial N fertilizer on sandy soils, but this application and any N fertilizer on any soil must be applied after March 1. Producers using N fertilizers must acquire certification through approved training programs. Producers must also report legal description of wells irrigating the crops, acres of each crop, and crop type. In addition, if planting corn, sorghum, and potatoes, producers are required to perform regular soil and water tests to monitor residual nitrogen and groundwater nitrate, report expected yields, apply credits for past legume crop and manure or sludge, and use University of Nebraska recommended N application rates. Producers must also monitor annual groundwater irrigation volume applications which may improve water use, lower need for higher fertilizer application rates and reduce nitrate-N leaching.

Table 2. Control phases and their corresponding groundwater nitrate concentrations.

Phases	**Concentration Range (ppm)**	**Qualifiers**
Phase 1	0-7.5	No municipal supply potentially adversely impacted
Phase 2	7.6-15.0	Municipal supply within a sub-region that is potentially impacted or vadose zone nitrates indicating strong potential for future groundwater quality problems
Phase 3	15.1≤	Municipal supply within a sub-region that is potentially impacted or vadose zone nitrates indicating strong potential for future groundwater quality problem
Phase 4	Areas where nitrate levels are not declining at an acceptable rate as determined by the Board of Directors. A determination will be made by reviewing the running 5-year average of a well or set of wells, and the anticipated time that would be required to reach a level of 10 ppm.	

Groundwater quality control phase 3 has the same requirements as phase 2 with two additional requirements. The first requires split application of fertilizer during the growing year. If more than 50% of the application is applied as pre-emergent, the producer is required to furnish certification from the dealer that an inhibitor was used at the recommended rate. Quality control phase 3 also prohibits commercial N fertilizer application on sandy soils until after March 1 and requires split application of fertilizer. Quality control phase 4 has all the same requirements as quality control phase 3, with three additions. The first addition is that the expected yield is to be set by the district. The second is that commercial N fertilizer applications must not exceed district recommendations and a copy of the fertilizer receipt must be submitted with the report. The final requirement for Phase 4 is that the NRD staff will work with the producer to improve nitrogen and irrigation management practices. For the ground water quality control program, the CPNRD has 1,393,902 acres phase 1 designation, 424,075 acres under phase 2 designation, and 320,352 acres under phase 3 designation (Table 4). There are no phase 4 zones throughout the district.

Table 3. Twenty-year average NO_3-N concentrations in groundwater samples and measured soil NO_3-N by control quality phases in the Central Platte Natural Resource District compared to the average vadose zone NO_3-N measured in the current study. Groundwater data retrieved from the Nebraska Clearinghouse Database.

Phase	Number of well samples	Average Groundwater NO_3-N (mg/L)	Standard Deviation (mg/L)	Number of samples	Average Vadose Zone NO_3N (μg/g)	Std Dev. (μg/g)	Total Acres
1	1,054	4.02	4.74	774	3.41	4.03	1,393,902
2	690	13.4	11.4	91	14.8	20.2	424,075
3	555	19.0	9.43	22	1.23	1.11	320,352

Table 4. Description of location ground water quality phase, irrigation method, and self-reported crop type and fertilizer application rates.

Site	GW Quality Phase	Irrigation Method	Crop Type (Self-Reported)	Fertilizer Application Rate (Self-Reported)
DH-19-15	Phase 2	Pivot	Corn/Seed Corn/Bean/Alfalfa rotation	1 ton of chicken manure - organic field for 8 years
DH-20-15	Phase 2	Pivot	Corn/Bean rotation	Average of 180 lbs/acre - field grid sampled every year, applied as recommended
DH-21-16	Phase 1	Pivot	Not Reported	Not Reported
DH-22-2-16	Phase 1	Pivot	Crop rotation	Actual N 230-240 lbs/acre every other year
DH-26-19	Phase 1	Pivot	Not Reported	Not Reported
DH-28-17	Phase 1	Gravity	Not Reported	Not Reported
DH-29-17	Phase 1	Gravity	Not Reported	Not Reported
DH-30-17	Phase 1	Pivot	Not Reported	Not Reported
DH-31-16	Phase 1	Pivot	Corn	Average 220 lbs/acre varies by nitrogen carryover from year to year using soil tests
DH-32-15	Phase 2	Pivot		
DH-36-16	Phase 1	Pivot	Corn/bean rotation	180-200 lbs-N/acre for corn
DH-37-18	Phase 1	Pivot	Not Reported	Not Reported
DH-38-19	Phase 1	Pivot	Not Reported	Not Reported
DH-39-19	Phase 1	Pivot	Not Reported	Not Reported
DH-40-18	Phase 1	Gravity	Not Reported	Not Reported
DH-41-18	Phase 1	Gravity	Not Reported	Not Reported
DH-47-15	Phase 1	Pivot	Corn/Seed Corn/Bean rotation	100 lbs-N/acre for seed corn and 220 lbs-N/acre for field corn
DH-48-15	Phase 1	Pivot	Corn/Seed Corn/Bean rotation	220 lbs-N/acre when continuos corn and 110 lbs-N/acre when corn/soybean rotation
DH-49-15	Phase 1	Gravity	Corn/Soybeans	Approximately 180 lbs-N/acre for corn
DH-50-20	Phase 1	Pivot	Not Reported	Not Reported
MSEA-3-17	Phase 3	Pivot	Not Reported	Not Reported
MSEA-6-17	Phase 3	Pivot	Not Reported	Not Reported
Rosenau-17-19	Phase 1	Pivot	Not Reported	Not Reported
RS-1-20	Phase 1	Pivot	Not Reported	Not Reported
RS6-17	Phase 1	Pivot	Not Reported	Not Reported
RS8-17	Phase 1	Pivot	Not Reported	Not Reported
RS9-17	Phase 1	Pivot	Not Reported	Not Reported

2.3 Summary of County Level Results

2.3.1 Dawson, Custer, and Phelps Counties

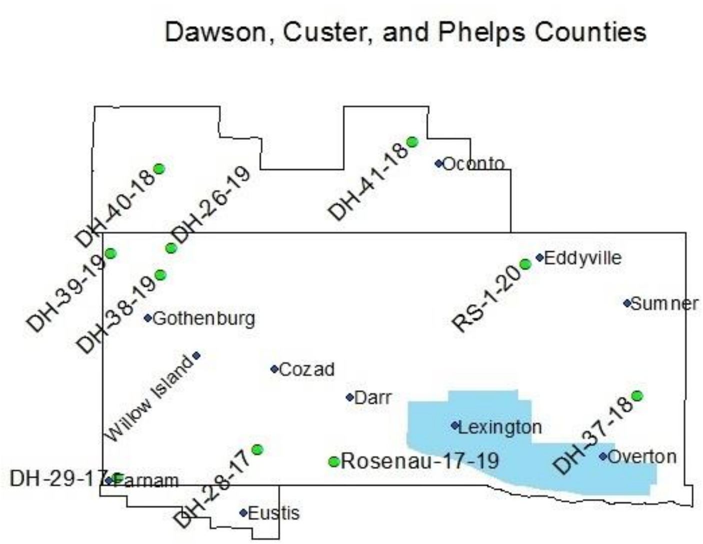


Figure 6. Sampling locations, groundwater management area phases, and nearby towns in Dawson, Custer, and Phelps counties.

In the western part of the district (Figure 6), 10 cores were collected between Dawson and Custer Counties. These cores were collected in 2017 (2), 2018 (3), 2019 (3), and 2020 (1). This part of the district has a single Phase 2 GWMA, but no cores were collected within the designation. In this area, both north and south of the Platte River have high silt content soils.

Site DH-26 is located in northwestern Dawson County, north of Gothenburg. The field had corn planted prior to sampling and is under pivot irrigation. The nitrate levels in this profile are low, but the total nitrogen storage decreased slightly by 128 lbs-N/acre from 631 lbs-N/acre in 1994 to 503 lbs-N/acre in 2019 (Table 6). The decrease is due to higher concentrations from two peaks at 40 and 50’ from 1994 that have been transported from the vadose zone (Appendix 1).

Site DH-28 is located in southern Dawson County, directly south of Cozad. It is under gravity irrigation (Table 4). This 2017 profile has two peaks of nitrate above the previous 1994 peaks, showing new nitrate leaching (Appendix 1). A peak in vadose zone nitrate indicated in 1994 is no longer present, so it has likely infiltrated into the groundwater. This location has relatively even water content throughout the profile, which makes the porewater NO3N graph shaped similarly to the soil NO3N. In the previous profile, this site had an estimated 6,627 lbs-N/acre in the vadose zone. The current estimate is 2,360 lbs-N/acre, showing a large drop of 4,267 lbs/acre (~64%) (Table 6).

Site DH-29 is located in the southwestern corner of Dawson County, a mile east of Farnam. This field is under gravity irrigation (Table 4). During coring, refusal was encountered at 140’ before reaching the water table. The nitrogen peaks near the top of the profile, in the top 10’, shows new storage (Appendix 1). No transport time estimates can be made because there are no discernable peaks in the top 140’ that can be matched between sampling events. In 1994, the total nitrogen storage was 2,999 lbs-N/acre for the same depth profile as the 2017 core, while in 2017 the total storage was 3,940 lbs-N/acre (Table 6). Despite having a shallower sample, the sampling interval at this location had an increase in total vadose zone nitrogen storage by ~31%.

Site DH-37 is located in eastern Dawson County, north of Overton, NE and the field is under pivot irrigation (Table 4). This site is also near the Platte River and has a relatively shallow water table of 48’. A comparison of each sampling period suggests moderate levels of nitrate-N storage in the vadose zone and porewater nitrate concentrations are below 10 mg/L. Total storage in 1998 of 388 lbs-N/acre compares to 268 lbs-N/acre in 2018 (Table 6).

DH-38 is located in northwestern Dawson County directly north of Gothenburg, NE and is under pivot irrigation (Table 4). Depth to groundwater is 70’ (Table 5). The total stored vadose zone nitrate-N in 1998 was 362 lbs-N/acre is lower than the estimated 462 lbs-N/acre in 2019 (Table 6). This site has relatively uniform nitrogen concentrations throughout the profile, with higher concentrations within the root zone and a slight peak from 10 to 20’ (Appendix 1).

Site DH-39, in the northwestern corner of Dawson County, is under pivot irrigation and the depth to groundwater is 108’ (Table 4, Table 5). The total stored vadose zone nitrogen in 2019 is 1,000 lbs-N/acre (Table 6). This site has lower overall gravimetric moisture content than other sites and generally higher porewater NO3N concentrations. One NO_3-N concentration peak at 38’ observed in the 1998 core appears to correspond to the peak at 80’ in 2019 (Figure 7). The apparent nitrate-N transport rate of 2 feet/year is consistent with other estimated vadose zone transport rates in south central Nebraska.

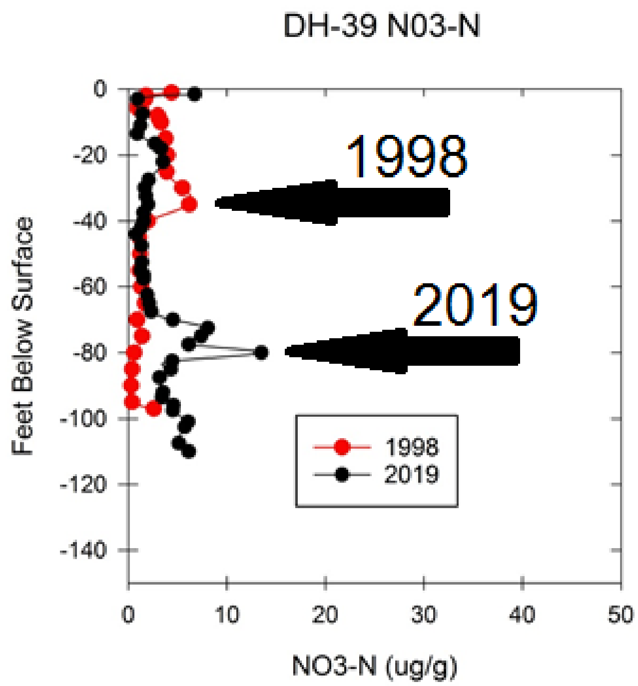


Figure 7. A comparison of vadose zone NO_3-N concentration peaks at DH-39.

Site DH-40 is located in southwestern Custer County, directly north of Gothenburg. This field is under gravity irrigation (Table 4). During coring the drilling rig hit refusal at 80' (indicating the no further penetration was possible) and did not reach the water table (Table 5). In 1998, the total stored nitrate-N was estimated to be 1,955 lbs-N/acre, while in 2018 the total storage decreased by ~34% to 2,693 lbs-N/acre (Table 6). NO_3-N concentration peaks could not be correlated to estimate transport rates.

Site DH-41 is located in southern Custer County, just northwest of Octono, NE and under gravity irrigation (Figure 6, Table 4). In 1998, the total NO_3-N storage was 803 lbs-N/acre, decreasing by about 23% to 620 lbs-N/acre in 2018 (Table 6). There are no peaks to estimate transport time, but due to high sand content within the profile, transport would be comparable to other sandy sites.

The Rosenau site is located in southern Dawson County, south of Darr, NE. During coring in 2017 the drill rig broke down at 80' depth, and the final 80'-110' was collected in 2019 to complete the profile. The field has been under pivot irrigation, with a total depth to water of 110' (Table 4, Table 5). When previously sampled in 1991, the total stored vadose NO_3-N was 817 lbs-N/acre decreased by 42% to 472 lbs-N/acre (Table 6). The nitrate-N concentration peak at approximately 5' below the surface in 1991 may correspond to deeper concentration peak at 70' in 2017 (Figure 8). Assuming these represent the same nitrate-N spike, the approximate transport rate would be 2.5 feet per year.

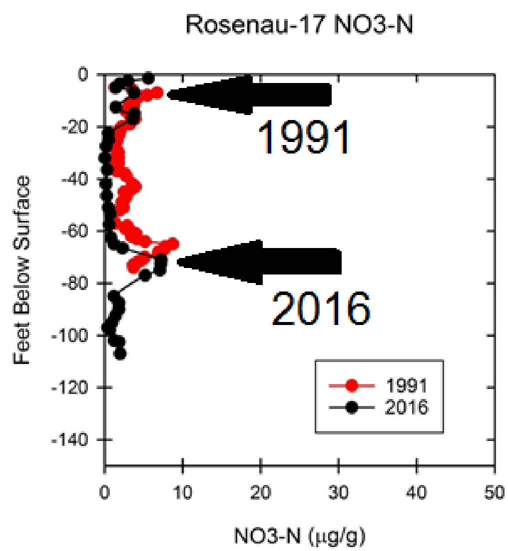


Figure 8. A comparison of vadose zone NO_3-N concentration peaks at location Rosenau.

Site RS-1 is located in northeastern Dawson County just west of Eddyville, NE. This field is under pivot irrigation with a depth to groundwater at 108' (Table 4, Table 5). In 1991, the total stored NO_3-N was approximately 250 lbs-N/acre, compared to 461 lbs-N/acre in 2020 at the same depth profile (Table 6). Higher concentrations were observed near the surface in 2020. This site has a consistently low NO_3-N concentration from 40' to the water table. The gravimetric moisture content fluctuates from high to low between 70' and 100', which in turn, leads to variable pore water NO_3-N in the same interval.

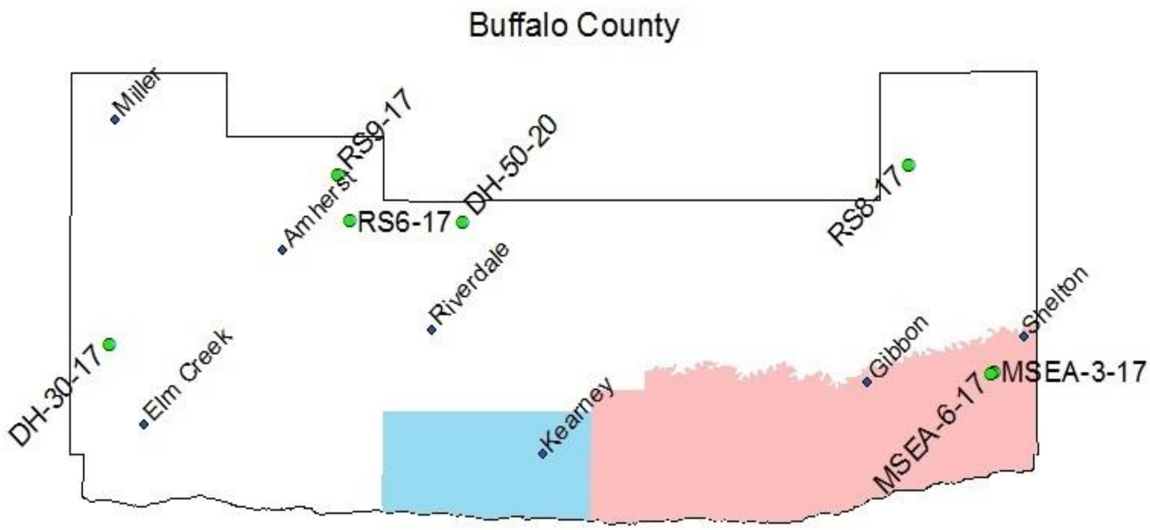


Figure 9. Sampling locations, groundwater management area phases, and nearby towns in Buffalo County.

2.3.2 Buffalo County

In Buffalo County (Figure 9), 7 cores were collected in 2017 and 2020. This area has both Phase 2 and Phase 3 GWMAs and both MSEA sites are within the Phase 3. In this area, the MSEA sites are close to the Platte River and lie within its valley. They were the shallowest sites of this project at 20' to groundwater and soils are well drained gravely sandy loam with high silt content at the surface.

Site DH-30 is located in western Buffalo County, north of Elm Creek, NE and under pivot irrigation with a water table near 65' (Table 4, Table 5). Stored vadose zone nitrate-N was 1,882 lbs-N/acre in 1994, compared to 2200 lbs-N/acre in 2016 (Table 6). Though this profile has variable concentrations, a peak nitrate-N concentration at 10’ in 1994 may potentially correspond to a peak at 65’ from 2016 and would be consistent with a

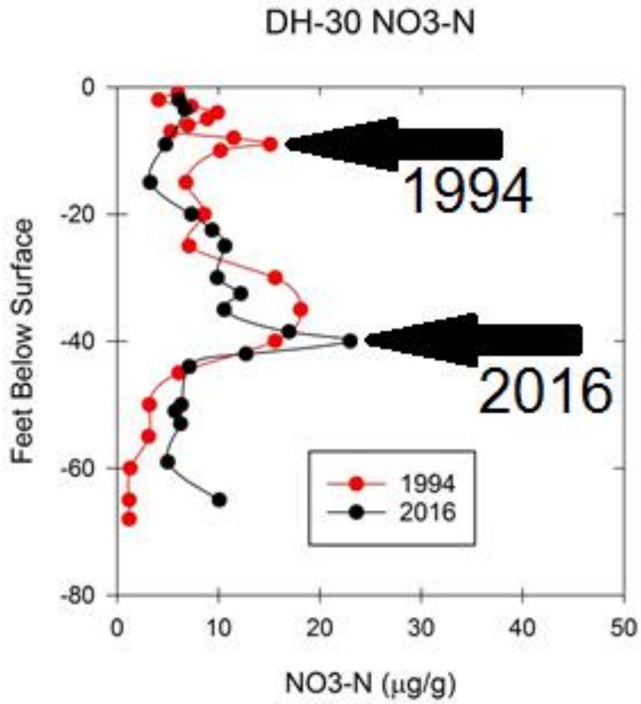


Figure 10. Comparison of vadose zone NO_3-N concentration peaks at location DH-30.

transport time of approximately 2.5 feet per year (Figure 10).

DH-50 is located in central Buffalo County north of Riverdale, NE and this field is under pivot irrigation (Table 4). The drill rig hit refusal at 149’ and was not able to penetrate to the water table (Table 5). This profile had a total estimate vadose nitrate-N of 1,220 lbs-N/acre (Table 6). This site was not previously cored.

MSEA-3 is one of two locations from a field in southeastern Buffalo County southwest of Shelton and located on the former Management Systems Evaluation Area (MSEA). This field is under pivot irrigation and the vadose zone is extremely thin with groundwater being at a depth of 20’ (Table 4, Table 5). The vadose zone is comprised mostly of sand and gravel, with the root zone being the only area with fine textured sediments and transport times would be very fast. With the high transport time and shallow water table, this field is under Phase 3 of the GWMA. In 1991, this core has a total storage of 107 lbs-N/acre compared to 71 lbs-N/acre in 2017 in the vadose zone (Table 6).

MSEA-6 is the second of two locations from a field in southeastern Buffalo County southwest of Shelton and this field is also under pivot irrigation. The vadose zone is extremely thin, with groundwater being at a depth of 20’ and a total stored of 88 lbs-N/acre was estimated at this location (Table 5, Table 6, Appendix 1). In 1991, there was a total storage of 76.4 lbs-N/acre, showing a slight increase of ~15%.

RS-6 is located in central Buffalo County east of Amherst, NE. This field is under pivot irrigation with the water table at 120’ (Table 4, Table 5). This site has low concentrations of NO3N from both sampling periods relative to other sites. In 2017, the larger concentrations are at the surface in the rooting zone and at 30’ in depth. Total stored vadose nitrate-N in 1991 was 734 lbs-N/acre increased to 858 lbs-N/acre in 2017 (Table 6). This site has no discernable NO3N peaks to estimate transport times.

RS-8 is located in eastern Buffalo County southeast of Ravenna, NE and is under pivot irrigation with the water table at 100’ (Table 4, Table 5). In 2017, this site had a lot lower NO3N concentration relative to 1991 (Appendix 1). This site also has a pretty constant gravimetric water content, which shows the pore water NO3N concentration graph shaped similarly to the NO3N graph. All values of pore water NO3N are under the MCL. In 1991, the total stored nitrate-N was 1,637 lbs-N/acre compared to 238 lbs-N/acre in 2017, showing the largest percent decrease of sampled sites at ~84% (Table 6). There are no discernable peaks to estimate transport times.

RS-9-17 is located in central Buffalo County northeast of Amherst, NE and is pivot irrigated with a depth to water at 115’ (Table 4, Table 5). In 1991, there was a NO3N concentration peak near 20’ below the surface which may correspond to a spike at 80’, suggesting a transport rate of 2.3 feet per year (Appendix 1). In 1991 total vadose nitrate-N storage was 1,420 lbs-N/acre (Table 6). Estimated storage decreased to 765 lbs-N/acre in 2017.

2.3.3 Hall and Howard Counties

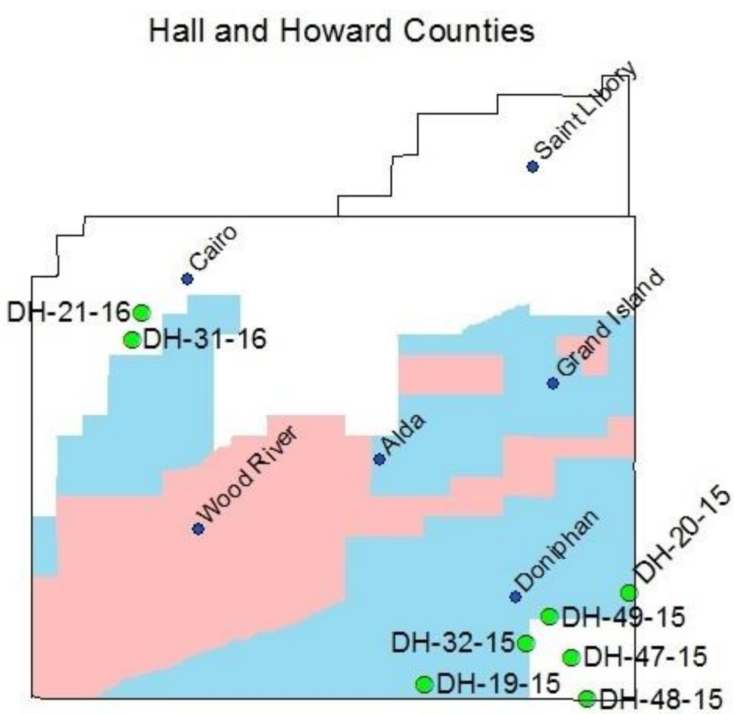


Figure 11. Sampling locations, groundwater management area phases, and nearby towns in Hall and Howard Counties.

In Hall County (Figure 11), 8 cores were collected in 2016. The Platte River cuts through Hall County (Figure 2), and these sites are characterized by a shallow water table and sandy surface soils (Figure 4). These highly permeable areas are overlaid with the

Phase 2 and Phase 3 GWMA's. In the southeastern corner of the state are 6 sampling locations with 3 locations being under Phase 2 (DH-19, DH-20, and DH-32). The other two sites are in the northwestern quarter of the county, just southwest of Cairo.

Site DH-19, in southern Hall County, is a field corn, seed corn, and bean rotation. Previously, the site has been used for alfalfa, and has been under pivot irrigation for about 40 years (Table 4). Over the past 8 years, the producer has switched to organic sources of nitrogen. In general, the producer applies one ton of chicken manure per acre, though not annually as the most recent application was in the spring of 2015. DH-19 is in a Phase 2 groundwater management area.

A nitrate-N concentration peak apparent in the 1994 profile around 60' may correspond to a similar peak now at 80' below the surface, suggesting a transport rate of around 0.91 feet per year (Figure 12). Sediments are clay to sandy loam with relatively low moisture content. Reduced water movement through this layer may be responsible for accumulation of nitrate above the water table. Between 1994 and 2016, the estimated change in nitrate-N storage from 8,023 to 8,860 lbs-N/acre corresponds to an increase of 10% (Table 6). The high concentrations of stored NO3N may have resulted from very high nitrogen application or spill approximately 50 years ago or the high concentrations could also be related to a "geogenic" or natural source of nitrate accumulation. This location should be resampled for analysis of organic nitrogen content, nitrogen isotope measurement and other indicators of a natural source. Irrigation over mobile geogenic nitrogen sources may still contribute to nitrate contamination of groundwater.

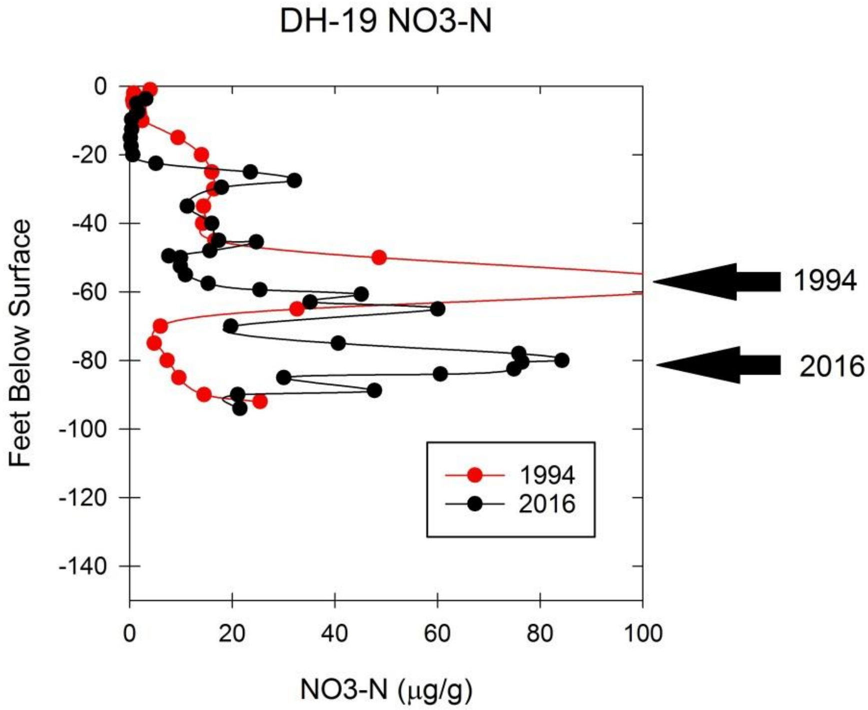


Figure 12. A comparison of vadose zone NO_3-N concentration peaks at DH-19. Apparent distance traveled was 20 feet at this location.

Site DH-20 is a pivot irrigated site in southern Hall County east of Doniphan, NE and has been in a corn and bean rotation for three to four years (Table 4). An average of 180 lbs/acre of fertilizer is applied to this field annually. The field has been grid sampled for several years, enabling controlled fertilizer application. The field has been under pivot irrigation since 1979. This site is also under Phase 2 of the groundwater management area. The NO3N concentrations throughout the profile in this site resemble the profile from the previous collection date (Appendix 1). There is a significant peak in ammonia-N concentrations, up to 12 μg/g between 25 and 30' below the surface which appears at the same depth as clay and silt loam layers. Total NO3N storage increased slightly by 30 lbs-N/acre (2%), from 1,730 lbs-N/acre in 1994 to 1,760 lbs-N/acre in 2016 (Table 6)

DH-21 is in northwestern Hall County southwest of Cairo, NE and has a depth to water of 119.8’ (Table 5). The field is under corn and bean rotation and under pivot irrigation (Table 4). A nitrate-N concentration peak at a depth of 65’ from 2016 may correlate with a peak identified at approximately 35’ from 1994. Using an elapse time of 22 years, the vadose nitrate-N transport time can be estimated at roughly 1.2 feet per year. In 1994, this location had 1,864 lbs-N/acre stored in the vadose zone, which increased by 316 lbs-N/acre to 2180 lbs-N/acre (Table 6)

Site DH-31 is located in northwest Hall County, southwest of Cairo, NE. The field is planted with continuous corn with an average of 220 lbs/acre of fertilizer applied annually, but this field is tested annually, and the amount of actual N applied depends on the carryover from the previous year (Table 4). For the past ten years this field has been pivot irrigated though the field was under gravity irrigation for the previous 35 years. The depth to water is 109’ (Table 5). This site had a 37% increase in stored NO3N, increasing from 1,674 lbs-N/acre in 1996 to 2,300 lbs-N/acre in 2016 (Table 6)

DH-32 is located in southern Hall County, south of Doniphan, NE, under pivot irrigation with a depth to water of 83’ (Table 4, Table 5). It is located in a Phase 2 groundwater management area. This is a very sandy vadose zone profile with potentially high transport rates. Elevated pore water NO3N concentrations generally occur beneath the crop root zone. Total vadose zone nitrate-N storage decreased in this location by 519 lbs-N/Acre, from 680 lbs-N/acre in 1996 to 161 lbs-N/acre in 2016 (Table 6).

Core DH-47 was drilled in a field in southern Hall County south of Doniphan, NE. It has a depth to water of 85’ (Table 5). It has under a rotation of corn, seed corn, and beans for the past 6 years, and for the past 15 years irrigated with a pivot system (Table 4). For the past two years cover crops have been used. When planted to seed corn, 220 lbs N/acre of fertilizer are applied, while field corn requirements are 100 lbs/acre. This site consists of sandy sediments with fine particle lenses. This site was not previously sampled. This site has an elevated NO3N content at the top of the profile at 3.7’ (Appendix 1). This is still in the root zone and still usable for crops. This location had 445 lbs-N/acre in the vadose zone (Table 6).

DH-48 is on the very southern edge of Hall County south of Doniphan, NE. This site has a depth to water of 75’ (Table 5). The field has been under a seed corn and bean rotation for 12 years (Table 4). Prior to these 12 years, the field was planted with seed corn for 35-40 years. As the field is currently planted, it receives 110 lbs/acre of fertilizer. When it was planted with commercial corn, the field received 220 lbs/acre. It has been under pivot irrigation for 40 years. This site was not previously sampled. This site has two smaller NO3N peaks at 18’ and 38’. This location had 1,070 lbs-N/acre stored in the vadose zone (Table 6).

DH-49 is located in southern Hall County south of Doniphan and was sampled in late March of 2016. In the prior crop year, the field was planted with soybeans. In recent years, the field has been under a corn and soybean rotation (Table 4). The field has been under gravity irrigation for 50 years. The producer estimates that out of these 50 years, 35 have been under corn crops. The sampling site is located close to the upper end of the field near the irrigation pipe, so there is a greater chance of N leaching at this end of the field. Soybeans are not fertilized, but corn receives approximately 180 lbs/acre. This site was not previously sampled. This site has a small NO3N peak in the top 1’ of the profile, so it is still available to crops. The variation in pore water NO3N can be attributed to a drop in gravimetric moisture content between 50-60’ (Appendix 1). This location had 621 lbs-N/acre stored in the vadose zone (Table 6)

2.3.4 Hamilton, Merrick, Nance, Polk, and Platte Counties

Two sites were cored in Polk County (Figure 13), and collected in 2016. Similar to Hall County, much of this part of the district is along the Platte River, resulting in the need for elevated GWMA phases. The two sites sampled were outside of this area and under Phase 1 requirements.

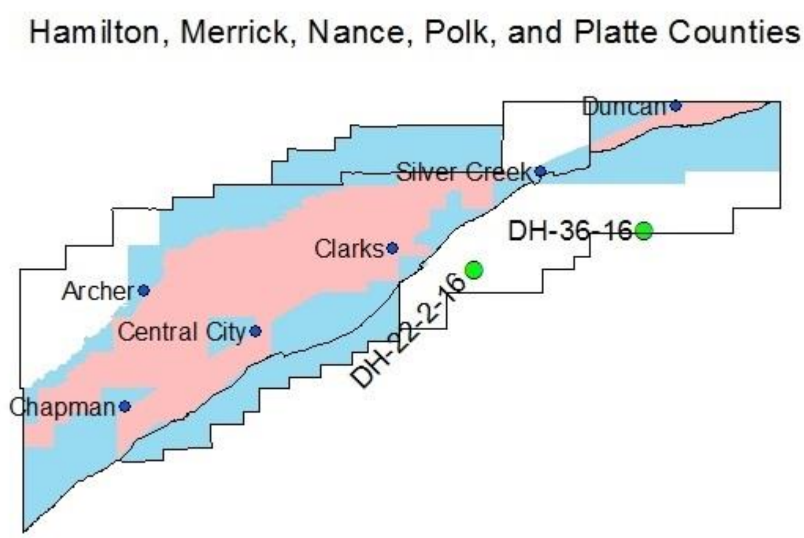


Figure 13. Sampling locations, GWMA Phases, and nearby towns in Hamilton, Merrick, Nance, Polk, and Platte Counties.

DH-22-2 is located in Polk County east of Clarks (Figure 13). The field is a corn and bean rotation and is under pivot irrigation (Table 4). The depth to water at this site is 113.5’ (Table 5). It has been 22 years since previously sampled, and with coarser sediments and only a thin clay layer. The producer reported applying between 230-240 lbs-N/acre. This site has a little nitrogen storage in the top 10’ of the profile and one small peak at around 85’ (Appendix 1). The peak from 1994 at around 15’ looks like it corresponds with the peak from 2016 at 85’, making an estimated transport time at around 3.2 feet per year. This transport time could be relatively slower due to the clay layer between 50-55’. In 1994, this location had 1,087 lbs-N/acre, decreasing by 164 lbs-N/acre to 923 lbs-N/acre in 2016 (Table 6).

Core DH-36 was collected in central Polk County, northeast of Osceola, NE, and is under a corn and bean rotation (Table 4). It has been irrigated with pivots for 36 years, and uses no-till management. It receives an average of 180-200 lbs/acre of nitrogen on the corn, while years with soybeans do not receive N fertilizer application. In 1985, 1993, and 2008 the field received 10-12 tons/acre of poultry manure. Increased clay and silt in the top half of the profile slows transport, though pore water nitrate is relatively high in the lower half of the core, partly due to low water content at this zone. Overall, there was a drop of total nitrogen by 1,539 lbs-N/acre (55%) from 2,799 lbs-N/acre in 1996 to 1,260 lbs-N/acre in 2016 (Table 6). This site was previously cored, but the data from the previous study is missing (CPNRD, personal communication). An interesting observation about this site, is the large NH4-N peak at about 40’ (Appendix 1). It is relatively atypical to see high NH4-N concentrations in the vadose zone that do not also correspond to elevated NO3-N concentrations.

Table 5. Site ID, sample dates, and depth to water table by county and sorted by Central Platte Natural Resource District groundwater quality phase designation. "Refusal" indicates that the water table was not reached.

Site	Sample Date	Sample Depth	Depth to the Water Table	GWMA Phase
Dawson, Custer, and Phelps Counties				
DH-26-19	12/11/19	79.5	79.5	Phase 1
DH-28-17	11/7/17	130.0	Refusal	Phase 1
DH-29-17	11/6/17	140.0	Refusal	Phase 1
DH-37-18	4/23/18	47.9	47.9	Phase 1
DH-38-19	4/23/18	70.0	70	Phase 1
DH-39-19	12/10/19	108.0	108	Phase 1
DH-40-18	4/23/18	80.0	Refusal	Phase 1
DH-41-18	4/24/18	110.5	110.5	Phase 1
Rosenau-17-19	11/8/2017 & 12/12/19	110.0	110	Phase 1
RS-1-20	1/14/20	108.0	108	Phase 1
Buffalo County				
DH-30-17	4/19/17	65.0	65	Phase 1
DH-50-20	1/15/20	149.0	Refusal	Phase 1
RS6-17	4/18/17	120.0	120	Phase 1
RS8-17	4/20/17	100.0	100	Phase 1
RS9-17	4/19/17	115.0	115	Phase 1
MSEA-3-17	11/14/17	20.0	20	Phase 3
MSEA-6-17	11/14/17	20.0	20	Phase 3
Hall and Howard Counties				
DH-21-16	11/16/16	119.8	119.75	Phase 1
DH-31-16	11/21/16	109.0	109	Phase 1
DH-47-15	3/30/16	85.0	85	Phase 1
DH-48-15	3/30/16	75.0	75	Phase 1
DH-49-15	3/31/16	69.9	69.9	Phase 1
DH-19-15	3/29/16	93.4	93.4	Phase 2
DH-20-15	4/6/16	59.8	59.8	Phase 2
DH-32-15	4/4/16	83.0	83	Phase 2
Hamilton, Merrick, Nance, Polk, and Platte Counties				
DH-22-2-16	11/15/16	113.5	113.5	Phase 1
DH-36-16	11/15/16	124.5	124.5	Phase 1

2.4 Methods

Soil cores were collected with a split spoon sampler, also referred to as a core barrel, in a hollow stem auger (Figure 14A). As previously stated, the cores that were sampled were part of a larger project assessing nitrate-N storage in the CPNRD. The split spoon sampler is essentially a 5’ tube that is split in half lengthwise to collect soil cores (Figure 14B). Inside of the sampler, there are two 2.5’ acrylic tubes that keep the soil sample accurately oriented and representing the *in situ* lithology. The core barrel is sent down through the hollow augers in order to negate the need to remove all augers for each 5’ sample. Once the core barrel is retrieved with the sample, it is taken apart and the acrylic liners are capped and labeled with the assigned location ID, depth, and orientation. Acrylic liners are then stored in Styrofoam coolers until they are brought back from the field and kept in a freezer at 0°F.

Cores are taken from the storage freezer and brought into the laboratory for processing. In the laboratory, core sections were removed from the freezer and allowed to defrost partially. Cores were divided into a maximum of 2.5-foot intervals for compositing. Shorter intervals were used where there was a visible change in lithology. For each subsample, a portion of the core that was representative of the entire sample was separated and returned to the freezer. Out of this remainder, a portion of fresh sample was taken for measurement of bulk density and water content (G. Philip Robertson et al., 1999). This is conducted by weighing a known volume, oven drying the sample for 24 hours at 105˚ C, and then reweighing the sample (Figure 14C, Figure 14D). The difference in weight represented the water content, which can be divided by the moist sample to determine gravimetric water content.

The remaining moist sample was homogenized and left to air dry overnight. The following day the air-dried soil was ground using a Wiley Mill (Figure 14E). For some cores, approximately 15 grams of each ground subsample was taken for an expodited particle analysis method (Kettler et al., 2001). Five grams were mixed with 5 mL of distilled water to measure sediment pH (G. Philip Robertson et al., 1999). Ten grams were mixed with a 1M KCl solution and loaded on a wrist action shaker for one hour to extract nitrate and ammonium (Figure 14F) (Diamond, 2003; Knepel, 2012). Extracts were preserved with sulfuric acid and batched for colorimetric analysis on a Lachat Quikchem 8500 flow injection auto-analyzer (Figure 14G). The quality of the analytical results was checked by analysis of method blanks, fortified blanks, and duplicates. A standard test soil was also extracted and analyzed with each batch of twenty samples.

Calculations for each parameter are listed in the table of contents and a summary of the average results for each core is provided in Table 7. Graphs of nitrate-N, ammonia-N, gravimetric moisture content, and pore water equivalent nitrate-N concentrations measured for each core are provided in Appendix 1.

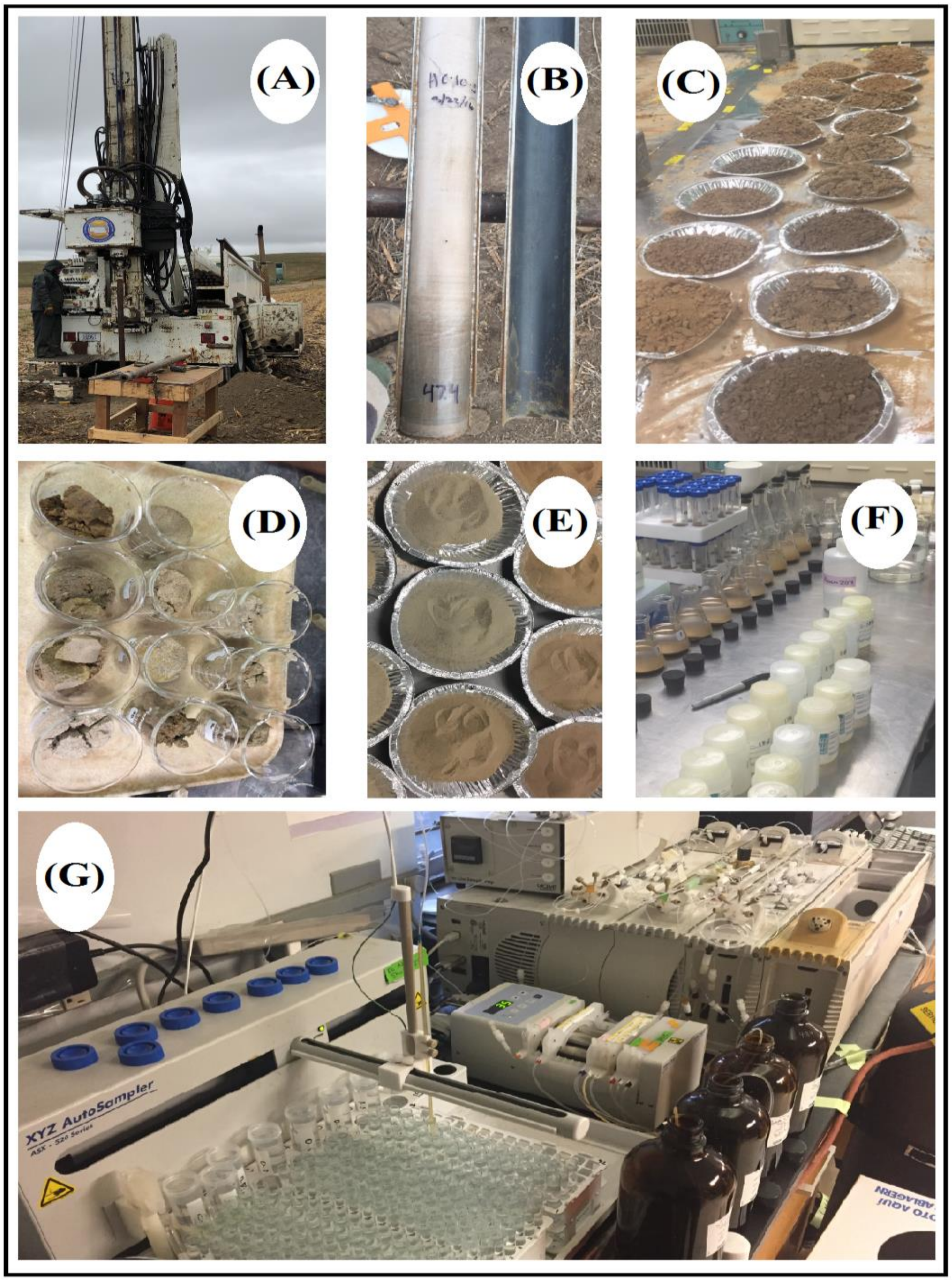


Figure 14. (A) shows the drill rig used for coring (B) shows the split spoon core barrel with the acrylic liners to contain soil samples (C) shows soil that has been broken down and homogenized based on changes in lithology (D) shows oven dried subsamples used for moisture content and bulk density measurements (E) shows homogenized, oven dried soil that has been passed through a Willey Mill (F) shows samples after shaking in a KCl solution for nitrate and ammonium extraction (G) shows KCl extracts being analyzed on a Lachat Quikchem 8500 FIA.2.5 Discussion

Cores were collected from across the CPNRD to characterize nitrate accumulation beneath a variety of agricultural practices, identify changed in stored nitrate-N under different land use and estimate nitrate transport rate by correlating concentration peaks. The depth of the water table ranged from 20’ to over 149’ (Table 5). Some coring locations had samples that penetrated into the saturated zone, presumably due to an indistinct water table. Vadose zone bulk density averages tended to be higher in the agricultural fields further away from the Platte River consistent with coarser sediment near the river, with an overall average bulk density of 1.48 g/cm3 (Table 7). DPT collected cores may produce a bias in bulk density measurements potentially due to compaction as the sample retriever is hammered into the vadose zone. However, because these vadose zone sediments were primarily sands, compaction was not found to be an issue for this project.

Individual profiles of gravimetric water content, ammonium-N, nitrate-N, and pore water nitrate-N are shown in Appendix 1. Profiles provide an indication of the variability in concentration versus depth, allow comparison to sediment texture, and show the relationship of vadose zone nitrate-N relative to the water table. For example, shallow samples of soil and pore water nitrate-N at sites DH-21, DH-22-2, DH-28, DH-29, and DH-40 (Appendix 1) show increased concentrations near the root zone, indicating current storage. The profiles DH-19, DH-20, and RS-9 show higher concentrations directly above the water table, showing previous nitrate-N storage that has leached through the profile.

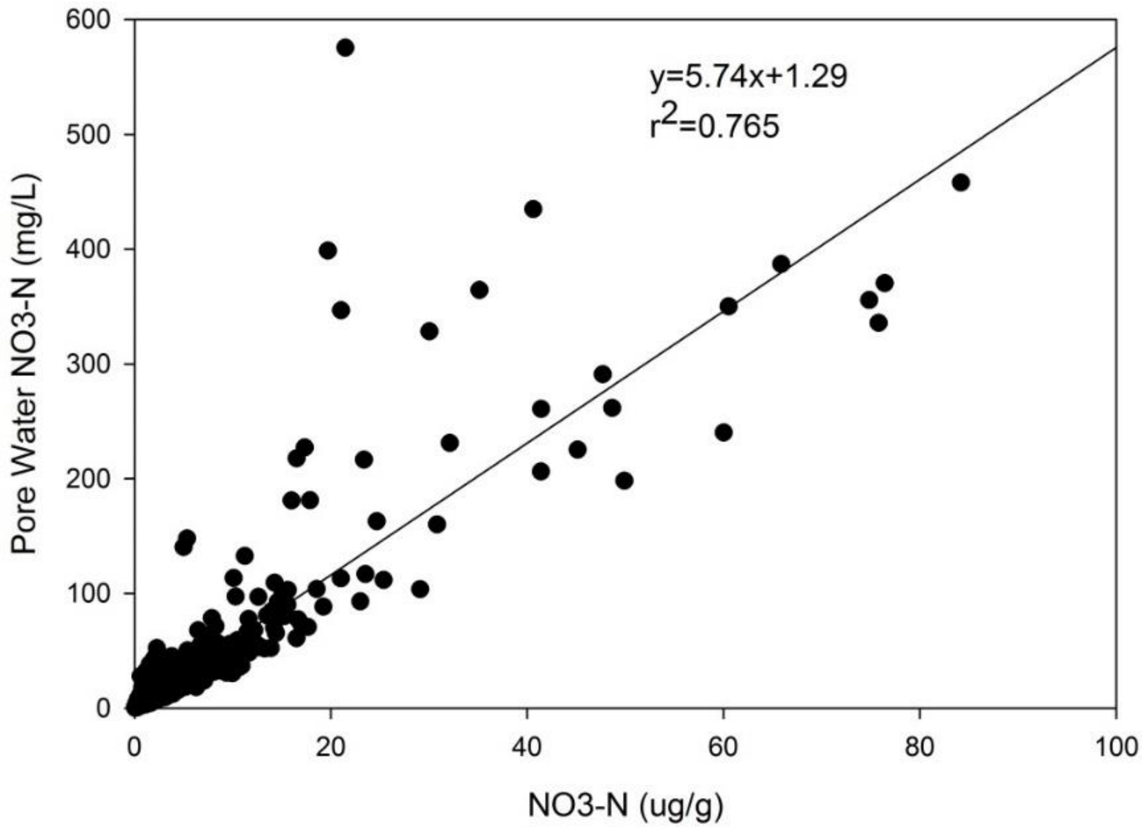


Figure 15. A scatter plot showing the correlation between NO3-N and pore water NO_3-N.

Average vadose zone nitrate ranged from 0.82 to 25.48 µg/g dry weight, while the pore water equivalent generally averaged between 3.78 to 186 mg/L (Table 7). Higher concentrations of pore water nitrate occurred in both the shallower portions and deeper portions, but majority were found at deeper depths at both of these locations. The highest pore water nitrate concentrations, up to ~575 mg/L, were found at DH-19 generally characterized as a vadose zone profile with high nitrate and low moisture content. Nitrate-N concentrations increased with depth in this location and appear to be moving downward. Because this profile contains very high levels of stored nitrate-N it would be useful to resample and better characterize sources of nitrogen and potential for movement. A comparison of difference in total NO3N estimates accumulation between the cores collected in the 1990s suggest that overall, there has been a 10% decrease beneath these locations (Table 6). The highest increase was in Buffalo and Dawson Counties with soils of higher silt content. Pore water NO_3-N correlates with soil NO_3-N (Figure 15) and may be used to illustrate relationships in the vadose zone to groundwater nitrate concentration. Porewater NO_3-N is calculated by dividing the NO3N content by the gravimetric moisture content. This shows that if a site has consistent moisture content throughout the profile, the pore water NO_3-N graph will look very similar to the soil NO_3-N graph.

Table 6. Comparison of total N accumulation in the vadose zone. Note: not all sites have historical data available and a negative value indicates a decrease in total storage. Average of the %change indicates a 58% increase in vadose zone nitrate-N. Comparison data for all sites are censored to within 5' for accurate comparison. Detailed estimates in Appendix 1.

Site	Previous Vadose NO_3N (lbs-N/Acre)	Current Stored (lbs-N/Acre)	Difference in Total Stored NO_3N (lbs/acre)	% Change in Total Stored NO_3N
Previously Cored Locations				
DH-19-15	8023	8860	+837	+10%
DH-20-15	1730	1760	+30	+2%
DH-21-16	1864	2180	+316	+17%
DH-22-2-16	1087	923	-164	-15%
DH-26-19	631	503	-128	-20%
DH-28-17	6627	2360	-4267	-64%
DH-29-17	2999	3940	+941	+31%
DH-30-17	1882	2200	+318	+17%
DH-31-16	1674	2300	+626	+37%
DH-32-15	680	161	-519	-76%
DH-36-16	2799	1260	-1539	-55%
DH-37-18	388	268	-120	-31%
DH-38-19	362	462	+100	+28%
DH-39-19	742	1000	+258	+35%
DH-40-18	1955	1290	-665	-34%
DH-41-18	803	620	-183	-23%
MSEA-3-17	107	71	-36	-34%
MSEA-6-17	76.4	88	+11.6	+15%
Rosenau-17-19	817	472	-345	-42%
RS-1-20	250	461	+211	+84%
RS-6-17	734	858	+124	+17%
RS-8-17	1637	238	-1399	-85%
RS-9-17	1420	765	-655	-46%
			Average	**-10%**
Newly Cored Locations				
DH-47-15	N/A	445	N/A	N/A
DH-48-15	N/A	1070	N/A	N/A
DH-49-15	N/A	621	N/A	N/A
DH-50-20	N/A	1220	N/A	N/A

Table 7. Average values of measurements from each coring location. Note: DH-19 is not included in the column averages*.

Site	ρb	θg	pH	NO_3-N (μg/g)	NH_4-N (μg/g)	Pore Water NO_3-N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
DH-19-15*	1.43	0.16	6.52	25.48	0.82	185.93	102.99	173.64
DH-20-15	1.43	0.20	5.91	15.90	2.89	94.67	63.13	112.39
DH-21-16	1.48	0.22	7.25	4.60	2.20	20.41	18.37	34.88
DH-22-2-16	1.63	0.17	7.47	2.00	1.22	13.56	8.65	17.08
DH-26-19	1.34	0.19	8.06	1.87	1.01	10.12	6.85	14.58
DH-28-17	1.50	0.16	7.71	4.79	0.89	29.10	18.47	38.29
DH-29-17	1.49	0.19	7.44	7.15	1.33	39.02	29.66	58.92
DH-30-17	1.55	0.21	7.01	9.16	1.03	50.79	38.30	53.43
DH-31-16	1.55	0.23	6.91	4.81	0.50	21.18	19.88	39.80
DH-32-15	1.53	0.16	7.04	0.64	1.08	3.89	2.60	4.31
DH-36-16	1.52	0.19	6.58	2.77	0.83	18.21	11.42	17.32
DH-37-18	1.32	0.26	7.92	1.50	1.07	5.99	5.47	9.26
DH-38-19	1.24	0.20	8.07	2.06	0.92	10.61	7.15	12.70
DH-39-19	1.31	0.16	8.20	3.44	1.06	21.69	12.46	26.19
DH-40-18	1.42	0.17	7.79	4.27	1.11	25.37	16.52	33.31
DH-41-18	1.48	0.20	7.83	1.64	0.93	8.98	6.48	10.57
DH-47-15	1.45	0.15	7.27	1.69	0.33	12.11	6.17	9.63
DH-48-15	1.46	0.18	7.13	3.65	0.88	21.05	14.13	28.28
DH-49-15	1.49	0.19	7.26	2.38	1.41	14.08	9.54	13.58
DH-50-20	1.37	0.20	8.04	2.41	1.29	11.76	8.92	20.06
MSEA-3-17	1.71	0.10	7.07	1.12	1.04	10.74	4.92	9.93
MSEA-6-17	1.54	0.18	7.55	1.35	1.29	7.23	5.45	9.33
Rosenau-17-19	1.45	0.16	8.07	2.08	0.89	11.55	7.84	14.38
RS-1-20	1.34	0.18	7.81	2.14	0.57	12.51	7.48	15.34
RS6-17	1.61	0.15	8.25	2.70	1.41	18.03	11.37	21.61
RS8-17	1.48	0.22	7.30	0.82	1.40	3.78	3.32	7.48
RS9-17	1.39	0.18	7.29	7.66	1.02	43.88	29.73	58.78
Average*	**1.46**	**0.18**	**7.43**	**4.45**	**1.13**	**26.90**	**17.68**	**32.04**

2.5.1 Comparison of stored N between pivot and furrow irrigated fields

Irrigation water use plays a significant factor in NO_3-N leaching in the vadose zone. Furrow irrigation, commonly referred to as gravity irrigation, uses a large pipe connected to a well to flood rows down the length of a tract of a field to irrigate crops. Larger water volumes are used to ensure that water reaches the end of the field, furrow irrigation has a higher potential to leach the highly soluble nitrate anions past the root zone. Pivot irrigation uses less water applied through sprinklers attached to a long series of spans. Using pivot irrigation allows producers to focus on deficit irrigation, making it easier to apply the amount of water that a crop needs, while not putting excess stress on groundwater resources. With the less water input from pivot irrigation, nitrate is more likely to stay in the root zone where it can still be used for crop growth.

A reduction in the amounts of irrigation water applied each year likely leads to a slower transport rate and a higher mean residence time of leached NO3N. Previous studies of the CPNRD have shown that when 15% of producers in a given area switched to pivot irrigation, groundwater nitrate levels also appeared to decline6. Once past the root zone, leached nitrate will generally move with recharge water and ultimately reach the water table. This shows that a large part of nitrogen management is water management6. For this project, both soil and pore water NO_3-N values were lower in pivot irrigated fields versus gravity irrigated fields.

A recent study from western Nebraska compared the residual soil NO_3-N concentrations of a root zone profile using both pivot and furrow irrigation methods at the end of a growing season. In Figure 16, end-of-season soil nitrate under pivot irrigation is represented by profile A and furrow irrigation if represented by profile B. This shows that under pivot irrigation, most residual NO3N remains in the top of the profile where it can be available for the crop. Under furrow irrigation, much of the NO_3-N is leached to the bottom of the profile and slowly becomes unavailable to the crop.

The deeper vadose zone shows evidence of higher leaching under furrow -irrigated fields. An average NO_3-N concentration of all samples under furrow for this study is 4.33 µg/g (σ=3.87; n=176). The average NO_3-N concentration of all samples under pivot irrigation is 3.42 µg/g (σ=5.32; n=674). These statistics show that on average, there is more NO_3-N accumulates beneath fields that are under furrow irrigation and eventually is transported to the water table. An earlier investigation at the MSEA sites found a similar trend between furrow and sprinkler irrigation that was followed up by a statistical comparison of groundwater nitrate concentrations and use of pivot irrigation in the Central Platte Natural Resources District.

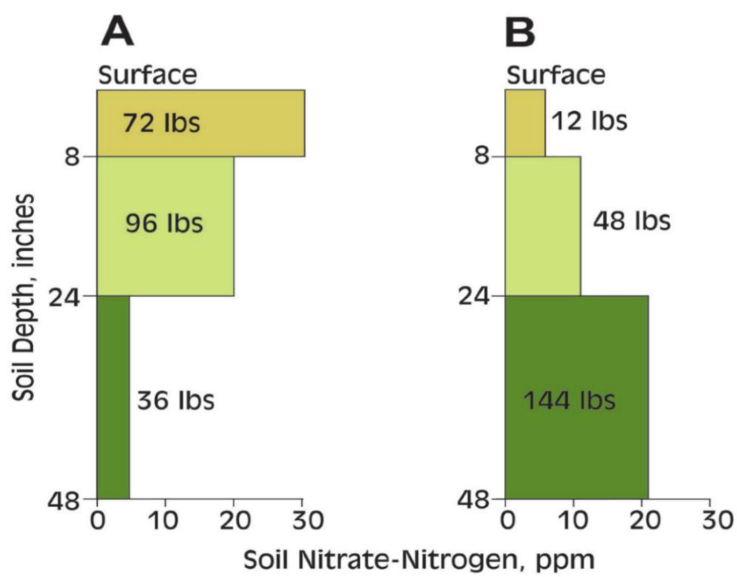


Figure 16. A scenario representing a comparison of NO_3-N concentrations at three different depth intervals for pivot (A) versus gravity (B) irrigation methods at the end of growing a season, from Hergert and Shapiro, 2015.

2.5.2 Sediment Hydraulic Conductivity

Saturated hydraulic conductivity values are both affected by soil and fluid properties. In the soil, there are a few factors that directly affect Ksat. First, the total porosity plays a major factor. If the soil has a high porosity, it will allow for a higher water flux. Inversely, if the soil is compacted and has low porosity, the water flux will be low. Another important factor is the tortuosity of the pore space, or the amount of twisting and bending the path of water must take. If a soil has low tortuosity, the flux will be higher than with high tortuosity. In this experiment, the fluid properties, water, are considered constant.

In this study, three samples were selected for measurement of hydraulic conductivity for use in future nitrate transport simulation. Intact sections from two cores were tested for Ksat (Table 8). DH-19 was sampled at a depth of 30’ and DH-47 was sampled from 29’ and 63.3’. All three samples had a soil texture that comprised of sandy loam which could be expected to have relatively high permeability. Despite all samples having the same textural description, the Ksat values all vary considerably. The variance can be accounted for due to soil properties beyond texture such as porosity and tortuosity. Measurement of the section of core DH-47 at 63.3’ indicates much lower Ksat value than at 29’, possibly due to factors such as compaction. These measurements indicate that at full saturation, water could be transmitted at rates 0.847 m/day, 1.55 m/day, and 0.00624 m/day for DH-19 30’, DH-47 29’, and DH-47 63.3’, respectively. The variation in Ksat values suggests that despite having the same textural class, other factors affect the Ksat values and ultimately, the transport times. However, as this is a measurement of saturated flow, the transport rate would be slower in an unsaturated soil due to capillary effects of water in soil. In unsaturated flow, moisture content from above would have to be transported down the profile in order to displace the pore water to continue leaching.

Table 8. Measured saturated hydraulic conductivity values.

Core ID	Sample Depth (ft)	Textural Class	Ksat (m/hour)	Ksat (m/day)
DH-19	30	Sandy Loam	0.0353	0.847
DH-47	29	Sandy Loam	0.0646	1.55
DH-47	63.3	Sandy Loam	0.00026	.00624

2.6 Quality Assurance Objectives

Quality assurance (QA) methods were conducted on all laboratory analyses. For nitrate and ammonia extraction there were four QA samples analyzed for roughly every 25 samples. These consisted of a replicate, a soil standard, a laboratory fortified blank (LFB), and a laboratory reagent blank (LRB). These protocols are used to help standardize and ensure proper functioning of laboratory methods and analytical instruments. A replicate is extracting one sample twice to ensure that the NO3-N and NH4-N concentrations are close. The standard soil has an unknown concentration, but it is compared to every QA standard to ensure they have similar concentrations. An LFB is the carrier, potassium chloride, spiked with a known concentration of NO3-N and NH4-N. An LRB is the carrier without a spike, which should read zero. If QA protocol was not measured within the acceptable range, samples were reextracted with new QA until data quality can be assured.

2.7 Conclusion

This study was conducted primarily to compare vadose zone nitrate occurrence with previously sampled locations to determine whether land use practices have affected nitrate levels over the last 30 years. Twenty-seven cores were collected from across five counties in the CPNRD. Cores were divided into subsamples and analyzed for numerous chemical and physical characteristics, such as: gravimetric moisture content, bulk density, texture analysis, pH, NO_3-N, and NH_4-N. These data were then used for calculated analyses, such as lbs-N/acre, lbs-N/acre-ft, and pore water NO_3-N. Select samples were further analyzed for particle analysis and Ksat samples.

Of the 4 different groundwater quality control phases, Phase 1, Phase 2 and Phase 3 were sampled and evaluated. Sandy soils along the Platte River generally comprise of the elevated phase levels, due to the larger sediment size, higher infiltration rates, and shallow water table. In this study, the water table ranged from a depth of 20' to over 149', with the two Phase 3 sites consisting of the 20' water table and sandy subsoil. Average NO_3-N samples ranged from 0.82-25.5 µg/g, with the pore water equivalent between 3.78-186 mg-N/L. Spikes of nitrate-N concentrations in the vadose zone were evident at core locations DH-19, DH-20, DH-21, DH-28, DH-30, DH-39, DH-50, Rosenau, and RS-9. Ammonia-N concentrations in the vadose zone were variable across the area averaging 0.33 to 2.89 µg/g NH_4-N. NH_4-N concentrations were generally lower than NO_3-N, but there were a few samples where NH4-N was higher. A 20-year average of reported ground water data from the Nebraska Clearinghouse Database was used to analyze average well NO_3-N concentrations in the 3 different ground water quality phases. Phase 1 wells had an average of 4.02 mg/L, phase 2 wells had an average of 13.4

mg/L, and phase 3 wells had an average of 19 mg/L (Table 2). The corresponding soil nitrate-N concentration average for phase 1 sites is 3.41 ug/g, 14.8 ug/g for phase 2, and 1.23 ug/g for phase 3. Average NO_3-N concentrations for MSEA-3 and MSEA-6 sites are a lot lower than the phase 2 sites. This is due to a shallow water table, 20', and a lower sample size, n=22. This shallow water table and small sample size lead to a lower concentration because the nitrate doesn't have as much depth to accumulate before it reaches the water table and stratifies. The phase 3 land that was sampled in this project is likely designated as such due to the very shallow water table and high sand content.

Porewater NO_3-N showed a wide range of values, inversely correlated to gravimetric moisture content and positively correlated with sediment NO_3-N. Samples with low moisture content generally had higher concentrations of pore water NO_3-N but no correlation was found between moisture content and nitrate. Of these twenty-seven cores, five were taken from locations with gravity irrigation, while the remaining 22 were taken from locations with pivot irrigation. In this study, supported by other published reports, the data suggests that locations with pivot irrigation have less nitrate storage in the vadose zone. Irrigation management plays a large roll in nitrogen management.

Overall, the mass of stored vadose zone nitrogen appears to be declining in the CPNRD, but it is still high relative to other vadose zone cores from throughout Nebraska. Repeat coring at the sites that have been sampled in 5-7 years may be useful for determining nitrate transport rates and evaluating changes in nitrogen storage in the vadose zone at these locations. Stable isotope analysis of selected samples in the vadose zone would be able to identify sources of nitrate at locations with high stored vadose nitrate. Determination of leachable geogenic trace elements such as arsenic and uranium may also be helpful parameters to investigate as it is becoming an increasing problem across the state. A more in-depth study of the vadose zone at location DH-19 on the cause of the very high NO_3-N concentration should also be conducted in order to determine the anomalous amount of nitrogen that was found in the vadose zone. Repeat coring at this location and taking additional cores throughout the field would help identify if this large concentration is an issue for part of the field or more widespread.

3. Evaluation of Nitrogen Transformation Potential In the Vadose Zone

Upon completion of the Central Platte Natural Resource District nitrate study, the occurrence of elevated concentrations of ammonium was investigated through a literature review showed gaps in the potential sources and processes. Important factors included trends in nitrogen use, nitrogen and carbon cycling in both the root zone and the vadose zone, and a look at other potential pathways to convert nitrate to ammonium. A deeper review of the literature helped narrow down the scope of this research and determine experiments required to find potential sources of this high ammonium content.

3.1 Literature Review

3.1.1 Trends in Nitrogen Use

Inorganic nitrogen is a macronutrient required for plant growth. Nitrate-N and ammonium-N are the only two forms of nitrogen that can be utilized by crops from the soil (Adelman et al., 1985). This necessity paired with the large agricultural industry in Nebraska shows why it has been so widely applied. Current levels of harvest yields, relative to historic yields, are only possible with the addition of nitrogen fertilizers (Adelman et al., 1985; Exner et al., 2014), which are needed to feed the growing population of the planet (Burow et al., 2010; Cao et al., 2018).

In soil, nitrogen can be found in both organic and inorganic forms. Inorganic forms are gaseous nitrogen (N_2), nitric oxide (NO), nitrous oxide (N_2O), nitrite (NO_2^-), nitrate (NO_3^-), and ammonium (NH_4^+) (Bremner, 1965; Hergert & Shapiro, 2015). Organic forms of nitrogen are generally derived from organic matter, such as animal waste and crop residue, and as amino acids and urea, which are broken down and incorporated by microbes (Hergert & Shapiro, 2015). Organic nitrogen in soil occur in forms that include ammonia (NH_3) and living cell components, such as amino acids, amines, proteins, peptides, and the bases of nucleic acids (Di & Cameron, 2002; Hergert & Shapiro, 2015). These different forms are cycled through biogeochemical processes. The nitrogen cycle in soils can play a role in both the potential loss to leaching, volatilization, and an increase of net storage through immobilization (Bouwman et al., 2002).

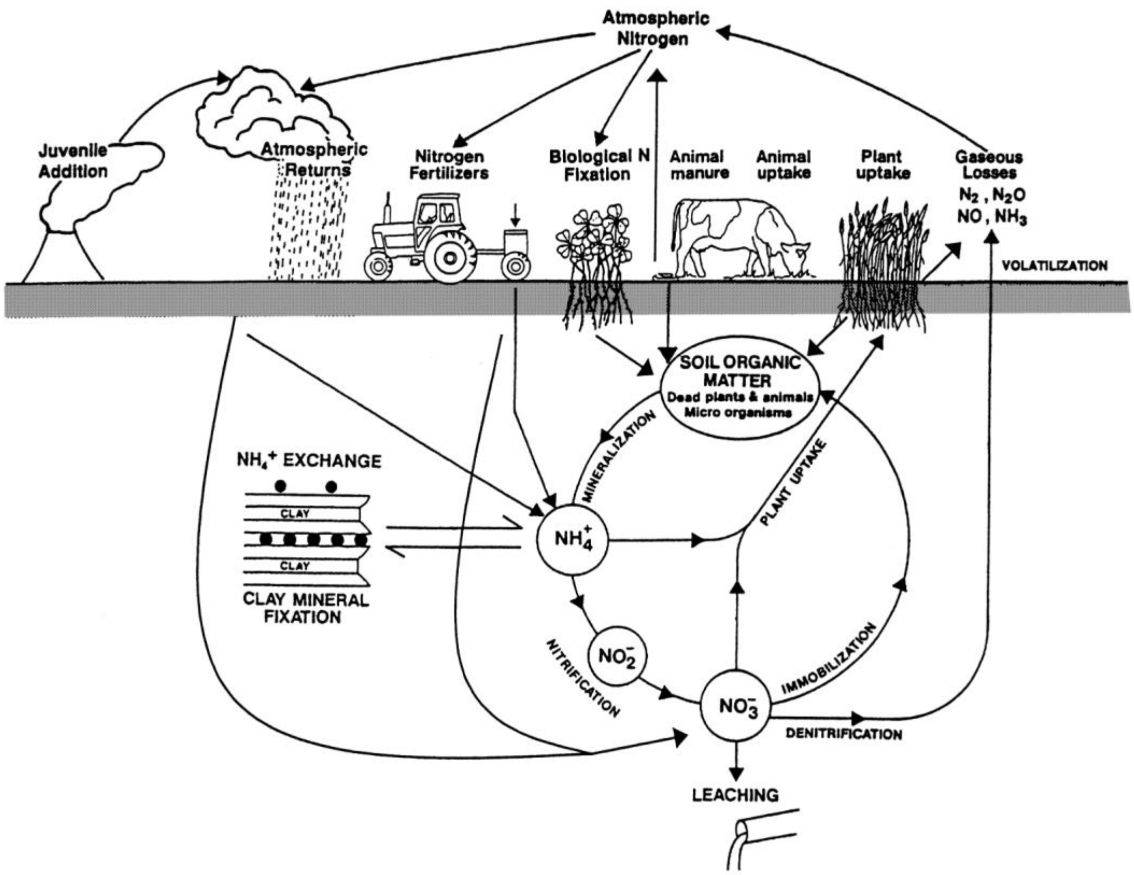


Figure 17. Diagram from Di & Cameron (2002) showing the soil nitrogen cycle, but not including dissimilatory nitrate reduction to ammonium (DNRA).

The nitrogen cycle begins as N enters the soil. Soil nitrogen input can be derived from atmospheric deposition, nitrogen fixation, rock weathering, and as a fertilizer addition (Figure 17)(Houlton et al., 2018). Nitrogen fertilizers are commonly applied to the field in the forms of manure/urea ($CO(NH_2)_2$), anhydrous ammonia (NH_3), or ammonium nitrate (NH_4NO_3). If the fertilizer is applied as anhydrous ammonia, a portion of it can be lost to the atmosphere as a gas through volatilization, and the remaining balance is converted to ammonium through hydrolysis (Bremner, 1965). Nitrogen can also enter the soil system via nitrogen fixation, when microbes convert atmospheric nitrogen into ammonia as microbes oxidize carbohydrates to gain energy (Denk et al., 2016; Hergert & Shapiro, 2015). This natural biological fixation occurs in both legume associated rhizobium and free-living microbes (Hergert & Shapiro, 2015). This biologically fixed nitrogen transforms into a more immobile form of plant or microbial biomass (Adelman et al., 1985; Denk et al., 2016). As this biologically fixed nitrogen decays from cell death or plant decomposition, it will end up associated within the soil organic matter pool (Denk et al., 2016).

Some microbes will mineralize ammonia into the inorganic and immobile form of ammonium. Ammonium can be used by microbes for energy in the process of nitrification. During nitrification, ammonium is oxidized into either hydroxylamine (NH_2OH) to nitrite, or directly to nitrite by ammonia-oxidizing microorganisms. Nitrite-oxidizing bacteria microbes complete the oxidation reaction converting nitrite to nitrate (Denk et al., 2016; Heil et al., 2016). At high pH values (pk_a 9.3), ammonium is converted to ammonia and potentially volatilize into the atmosphere (Denk et al., 2016). Both nitrate and ammonium can be taken up by plants and cycled back through the process, but ammonium is more easily assimilated by plants due to a higher energy consumption associated with nitrate reduction (Lu et al., 2013; Smirnoff & Steward, 1985). Nitrate can be lost to both groundwater, via leaching through the root and vadose zone, or into the atmosphere through denitrification (Adelman et al., 1985). Denitrification is the process of nitrate used as an electron acceptor instead of oxygen in anoxic conditions, and being reduced to nitrite, nitric oxide, nitrogen dioxide, and dinitrogen, stepwise (Denk et al., 2016).

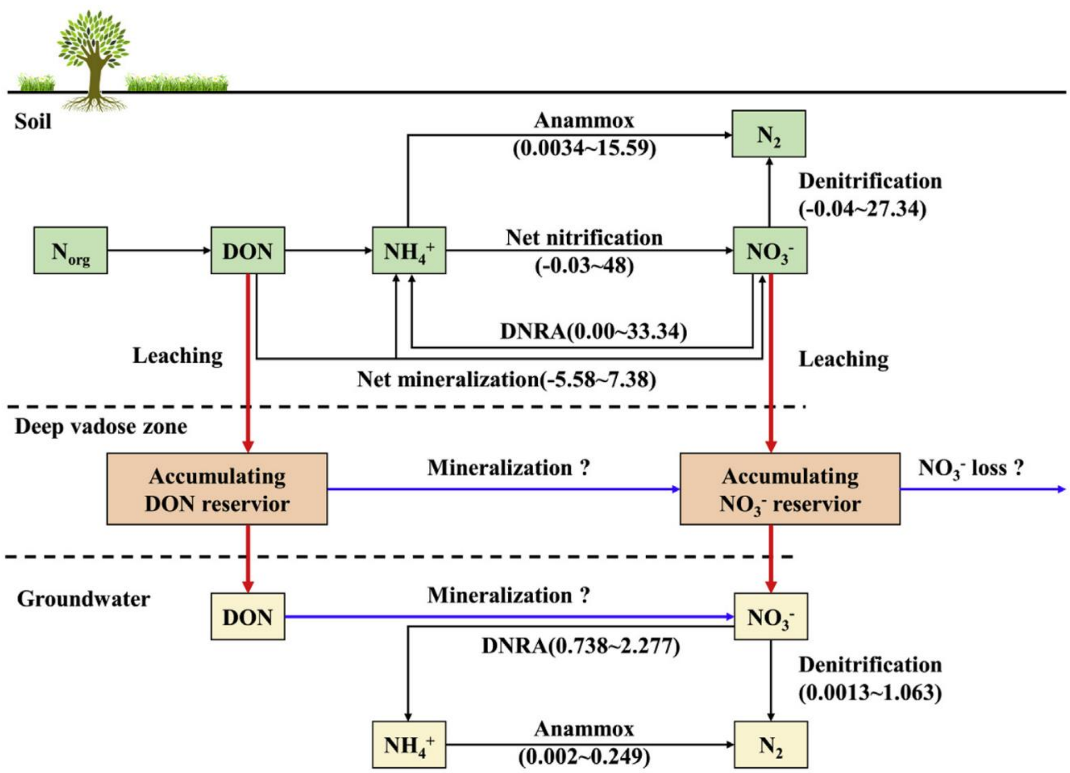


Figure 18. A figure from Xin et al. (2019) showing the major N transformation pathways and transformation rates (μg-N g-1 d-1) including DNRA.

A lesser studied, but critical, pathway for nitrogen in soil is by dissimilatory nitrate reduction to ammonium (DNRA) (Figure 18) (Denk et al., 2016; Putz et al., 2018). DNRA is a microbial mediated dissimilatory process that converts nitrate into less mobile, but biologically available ammonium that can be assimilated into cellular constituents (Burgin & Hamilton, 2007). In DNRA, nitrate is first reduced to nitrite, then hydroxylamine as an intermediate product, and then further reduced to ammonium (Denk et al., 2016). In this reaction, DNRA transfers eight electrons per mole of nitrate, while denitrification transfers five, resulting in the conclusion that DNRA is favored in environments with higher ratio of labile carbon to nitrate (Fazzolari et al., 1998; Lu et al., 2013).

Researchers disagree if the process is fermentative or respiratory, but they are theoretically mutually exclusive (Burgin & Hamilton, 2007; Lu et al., 2013; Tiedje, 1988). This process is dependent on both microbial conditions as well as soil conditions, such as a necessity of a high labile carbon content environment for fermentation, and low carbon-limited environments for respiratory denitrification (Burgin & Hamilton, 2007; Lu et al., 2013). One study that assessed the distribution, transformation, and budget of nitrogen in the vadose zone noted the difficulty determining the rate of DNRA using ^{15}N tracing incubation due to high background rates of dinitrogen gas, but noted that the potential rates and contributions of different nitrate reduction pathways can still be conducted using a slurry-based ^{15}N tracing method (Xin et al., 2019).

3.1.2 Root Zone Nitrogen and Carbon

Most of the research on soil carbon and nitrogen focuses within the root zone, as deeper sampling and experimentation adds another dimension of difficulty to the studies (Jones et al., 2018). Soil carbon and nitrogen cycles overlap the most within the root zone. Microbes break down and convert different organic compounds, assimilating both carbon and nitrogen, before ultimately releasing the elements back into the environment. Soil nitrogen transformations in the root zone are subject to different processes that depend on several factors including pH, temperature, soil organic matter (SOM), and the presence of microbes (Kadyampakeni et al., 2018).

Nitrogen transformation in soil is strongly controlled by pH, but also have the potential to effect pH depending on the form of nitrogen. The optimum pH for the nitrification process, where ammonium is converted to nitrate, ranges from 6.5-8, and is significantly decreased at pH <6 or >8.5 (Buss et al., 2004). This process is a major source of soil acidity (G.P. Robertson & Groffman, 2015). Other research shows that DNRA and mineralization occurred in two soils with different pH levels, a neutral site (pH 6.2) and an alkaline site (pH 82.), but was negligible in an acidic (pH 4.7) soil (Zhang et al., 2015). However, SOM is able to act as a buffer for pH.

Organic matter carbon as well as nitrogen are most crucial as a substrate for microorganisms and enters the soil in many forms. First, plants contribute a great deal of carbon from litter decomposition. Isotope analysis has shown that root derived carbon is found in soil and in microbial biomass in larger quantities than carbon derived from above ground sources, such as leaves and other litter (Schmidt et al., 2011). Most of this organic carbon is retained in the surface soil (0-30 cm) and is stabilized against microbial decomposition by occlusion in aggregates and interactions with soil mineral compounds by aggregation (Schmidt et al., 2011). Soil clay content is one of the factors known to play a role in stabilizing organic carbon due to the high specific surface area, cation exchange capacity, and ability to maintain soil moisture of clay sized particles (Rasmussen et al., 2018). Other factors include the amount of extractable metals and the climate (Rasmussen et al., 2018).

Physical and chemical properties of the landscape also play a large role in carbon storage. In soils, microaggregates, which are spatial units consisting of mineral particles and organic matter, are defined by a size smaller than 250 μm in diameter (Totsche et al., 2018). These microaggregates are able to withstand destructive forces that can break apart larger aggregates. Due to their stability, microaggregates can sustain in soils for decades (Totsche et al., 2018). These microaggregates stabilize soil organic matter and increase residence time by allowing for an increase in interactions between the mineral surfaces of soil particles and the organic matter.

The climate conditions that affect carbon storage in the root zone are mainly temperature and water content (Rasmussen et al., 2018; Wiesmeier et al., 2019). In soil, moisture drives plant production and with the addition of water through precipitation and irrigation, plants are able to grow and produce more biomass, increasing the litter at the end of its growth cycle. Too much or too little water content can also reduce microbial activity and substrate mobility, leading to a higher accumulation of organic matter (Wiesmeier et al., 2019). Water is also a key factor in weathering soil parent material and creating freshly weathered mineral surfaces that can help stabilize organic carbon (Wiesmeier et al., 2019).

Temperature also plays a large factor in decomposition of the soil organic matter. At cooler and drier conditions, microbial activity decreases decomposition on soil organic matter, therefor, at higher temperatures and higher moisture, there would be less organic matter present, as decomposition would be occurring more readily (Wiesmeier et al., 2019). In soils, studies have shown that changes in soil temperature and temperature gradients were highest in the top one meter of the profile, with the variations decreasing with depth (Zheng et al., 2020). Conversely, seasonal microbial variations increase with depth (Cannavo et al., 2004). In winter, as the freezing front increases, it changes the soil matric potential near the frozen boundary and spurs the soil water to flow towards the front, increasing moisture content at the frozen boundary. This change in water movement has implications on the seasonal variation of both nitrate and carbon transport through the root zone.

Total organic carbon (TOC) is the total amount of organic carbon in soil that can be described as a complex mixture of organic residues in different stages of decay (Miltner et al., 2012). Sources of TOC include soil fauna, plant biomass, both above and below-ground, but primarily from root mass, root exudates, and microorganisms. At the soil surface, plant derivatives and compounds are more abundant sources of carbon than microbial components. However, as depth increases, this relationship becomes inverse (Kaiser & Kalbitz, 2012). These different SOM compartments have a wide range of mean residence times, ranging from less than one year to well over one thousand years (Schmidt et al., 2011). On the higher end of this time scale, SOM can be stabilized by two processes, which include physical stabilization and chemical stabilization (Mikutta et al., 2006). Physical protection relies on the formation of aggregates and protection from occluded organic matter and chemical protection occurs when the organic matter interacts with mineral surfaces (Marschner et al., 2008).

As SOM continues to decay, it will be converted to different fractions. Starting with plant material, microbes will decompose it into smaller, less complex molecules. These consist of DNA/RNA, lipids, proteins, cellulose, hemi-cellulose, and lignin (Miltner et al., 2012). From this point, these compounds can either be further degraded and reduced in size by microbes, or they can be converted into microbial biomass. As the microbes die, the cellular and cell wall components become SOM and are prone to further decomposition. As this SOM decays, the original carbon sources can be identified by the stable carbon isotope composition of organic carbon (^{13}C-OC).

The stable ^{13}C is measured as a ratio of ^{13}C:^{12}C (i.e. $\delta^{13}C$) and is reported in parts per thousand (‰). In the natural environment, ^{13}C accounts for roughly 1.11% of the total carbon composition, while ^{12}C accounts for nearly 98.89%, and ^{14}C accounts for 10^{-10}%. As ^{13}C is a heavier isotope than ^{12}C, both plants and microbes discriminate against ^{13}C, as it requires more energy to process and assimilate the heavier isotope (Boström et al., 2007). For plants, C_3 type plants discriminate stronger against ^{13}C, than C_4 plants. This natural discrimination allows for a type of tracer for the source of carbon, based on its $\delta^{13}C$ signature (Marschner et al., 2008). Examples of C_3 plants include small seeded cereal crops, such as soybeans and wheat. Examples of C_4 plants include broadleaf plants, such as grasses and corn.

As a tracer, $\delta^{13}C$ of organic carbon can be help to differentiate the original source of the carbon. $\delta^{13}C$-OC values between -22 to -32‰ are typical for C_3 plants, while $\delta^{13}C$-OC values between -10 to -16‰ represent C_4 plants (Boström et al., 2007). The less negative values show an enrichment of ^{13}C-OC relative to ^{12}C. As a tracer, less negative values tend to occur in carbon sources derived from a C_4 plant. Another potential source of a higher $\delta^{13}C$-OC composition can come from microbial decomposition (Boström et al., 2007). As microbes also discriminate against the heavier ^{13}C in favor of ^{12}C, in areas where there are elevated $\delta^{13}C$, it could also be a sign of microbial decomposition occurring.

Dissolved organic matter (DOM) is a very fine portion of microbially derived, heavily degraded SOM. DOM accounts for a very small proportion of SOM (1-3%), but it is highly reactive, very mobile, and has a high ecological relevance (Kaiser & Kalbitz, 2012). DOM is generally considered to be within the size range of 0.22-0.7 µm in size, but for this thesis, DOM is considered to be <0.45µm. This size makes it too small to be filtered out of a pore water sample. As DOM percolates down the profile, it can become adsorbed and precipitate with clay minerals. At the soil surface, DOM is generally associated with plant derived compounds, but this decreases with depth. Inversely, deeper DOM is associated more with microbial compounds than with plant derived (Kaiser & Kalbitz, 2012). In oxygen limiting conditions, decomposition of DOM would decrease decomposition of this labile carbon source, but not slow transport. Preferential flow pathways play a large role in direct transfer of DOM past the top layers of soil.

Nitrate in soil can be taken up by crops or become lost to the plant by leaching through the soil, into the vadose zone, and ultimately contaminate the ground water. Carbon is also able to follow this leaching pathway and enter the intermediate vadose zone. Much of this nitrogen and carbon cycling in soil occurs via microbial processes (Denk et al., 2016; Rees et al., 1995). A vast majority of research has been done to study microbial processes in the surface soil and wastewater effluent systems, but little research has been done in the deeper sediments of the vadose zone (Buss et al., 2004; Holden & Fierer, 2005).

3.1.3 Intermediate Vadose Zone Nitrogen and Carbon

The vadose zone is comprised of the soil and sediments above the water table and below the land surface (Figure 4). It acts as a natural filter, attenuating chemicals and acting as a medium for reactions to take place (Keesstra et al., 2012). The intermediate vadose zone occurs below the plant root zone and above the water table. By studying the vadose zone, researchers can have an early detection for what they expect to ultimately reach the water table.

Nitrate is capable of being readily leached through the profile (Rees et al., 1995). As an anion, nitrate will not adsorb with the negatively charged clay particles and will move readily with soil water (Rees et al., 1995). Ammonium, a cation, will have a slower transport as it will adsorb with the soil mineral phase through cation exchange (Cather et al., 2012; Di & Cameron, 2002; Fronczyk et al., 2016). At neutral pH values typically found in soil, ammonium sorption is generally controlled by cation exchange pathways (Buss et al., 2004). Mixed-layer clays generally adsorb more ammonium, followed by two-layer clays and single-layer clays, respectively (Buss et al., 2004).

In the sediments of the vadose zone, there is also a potential for geogenic, or naturally occurring, nitrogen content found in rocks. This lithospheric nitrogen pool is the largest terrestrial pool in the global nitrogen cycle (Holloway & Dahlgren, 2002). This pool is relatively inactive when compared to other terrestrial pools, but undergoes different pathways to become introduced into the other more active pools. Elevated nitrogen content can be found in nearly every type of rock. In sedimentary rocks, this nitrogen content is generally accumulated form ancient basins where plants, soil, and microbes became trapped (Houlton et al., 2018). The nitrogen can take on both organic and inorganic forms, but is most commonly found as ammonium where it is incorporated into the interlayers of minerals (Holloway et al., 1998).

The weathering of these nitrogen rich rocks can directly translate to elevated nitrogen content in terrestrial soils and surface waters as the rock becomes more weathered (Holloway et al., 1998; Houlton et al., 2018). There is an area in the CPNRD that consists of some of this naturally occurring geogenic nitrate in southwestern and central Nebraska (Figure 19) (Boyce et al., 1976). The weathering on these zones depends directly on the mineralogy of the parent material.

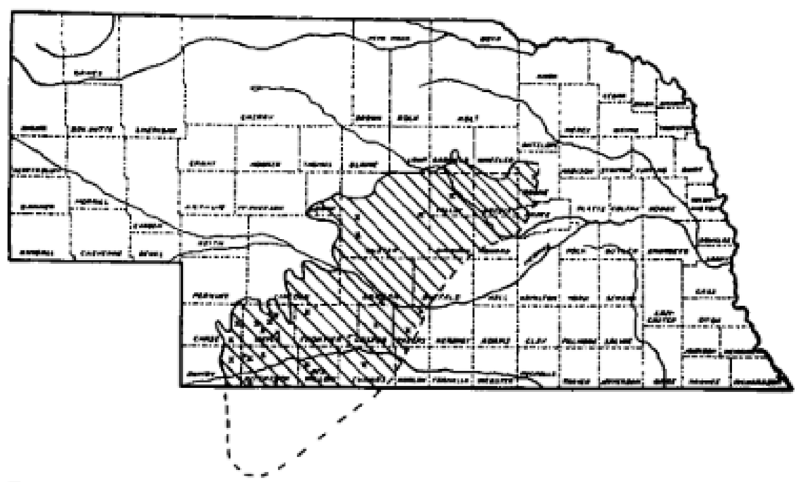


Figure 19. Boyce et al. (1976) shows approximately where the geogenic nitrogen is found in a Pleistocene loess in the vadose zone.

SOM is required to provide a source of carbon for microbes and helps provide a source of energy for other soil organisms (Loveland & Webb, 2003). In the vadose zone, some form of carbon would be required if there was any form of microbial cycling. Studies have shown that there are high correlations between carbon content and microbial biomass across a range of soils (Holden & Fierer, 2005).

3.1.4 Soil Water and Transport Dynamics

In the vadose zone, water content is one of the key factors affecting nitrogen dynamics, influencing permeability, diffusivity, and microbial activity (Mekala & Nambi, 2017). In Nebraska cropland, this water primarily originates from both precipitation and irrigation practices. Groundwater fed irrigation initially started in central Nebraska in the 1930's (Ferguson, 2015). One of the two main irrigation methods is furrow irrigation, where the crop rows are mounded in a field covering a slight gradient. These channels are then flooded, allowing the water to run down the rows and allow water to percolate into the soil. Under furrow irrigation, more water is generally used to irrigate than the root zone can hold, resulting in nutrient leaching into the intermediate vadose zone (Hergert & Shapiro, 2015).

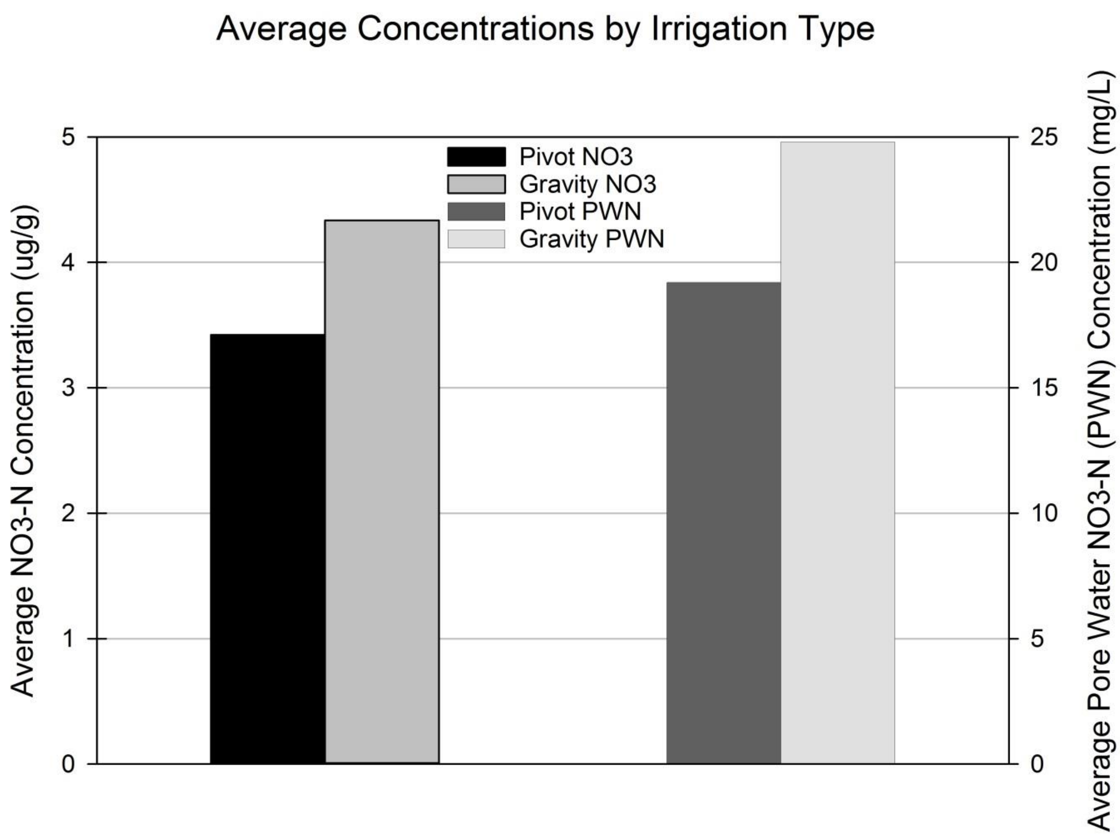


Figure 20. This graph shows a comparison of average nitrate-N and pore water nitrate-N based on irrigation method from the 2016 Central Platte Natural Resource District study. Note: Pivot n=674; Furrow n-176; DH-19 is not included in this comparison.

The other method is center pivot irrigation, where a series of connected sprinklers pivot around a well and water the field. This method allows for a greater focus on deficit irrigation, where water is only added in the amount that the plant requires for growth. Center pivot irrigation should allow for relatively little percolation of water and result in fertilizer remaining plant available in the root zone (Hergert & Shapiro, 2015) as well as maintain aquifer saturation levels. In the 2016 CPNRD study, the pivot irrigated fields showed both a lower nitrate-N and pore water nitrate-N concentrations than gravity irrigated fields (Figure 20).

Preferential flow paths, such as natural cracks between soil aggregates and macropores from fauna or decaying roots, play a large part in acceleration of water and solute through the vadose zone (Garg et al., 2005; Jardine et al., 2006). Preferential flow through macropores combined with the presence of relatively smaller micropores result in an unbalanced solute transport through the vadose zone (Garg et al., 2005). A study conducted on soil macropores account for a mere 0.32% of the total void in finer textured surface soils, but can be responsible for up to 96% of the total water movement (Mohanty et al., 2015). An implication of increased infiltration could be the potential for this increased flux allowing different solutes, such as ammonium, to bypass the electrostatic attraction that would normally bind ammonium to clay minerals or immobile organic matter. Studies have found variable transport rates of nitrate are likely due to changing fertilizer application rates, methods of irrigation, sediment conductivity, and the processes that affect nitrate transformation (Di & Cameron, 2002).

In addition to nitrate, DOM also has the ability to percolate through the vadose zone with infiltrating pore water. As the solute moves down the soil profile carrying DOM, it has the potential to be adsorbed and chemically bound or complexed to soil mineral phases by different processes (Jardine et al., 2006). The remaining DOM can be transported down the profile or used up by microbes and other soil organisms and lost as CO_2 gas (Holden & Fierer, 2005).

As the solute is transported down the profile towards the groundwater, different lithological formations will allow for different permeability. In the CPNRD, much of the surface soil is comprised of silt loam, but much of the subsurface consists of coarser sand materials with intermitted layers of clay. These courser materials allow for a higher infiltration rate. However, the clay layers can act as aquitards, disallowing water infiltration and creating a perched water table (Figure 1). As water pools on top of these layers, lateral flow is possible. Generally, in the vadose zone, this lateral flow is assumed to be negligible.

These measurements of flux can be predicted using pressure plate experiments to measure hydraulic conductivity. In the CPNRD study, three sandy loam samples from different depths at two locations were analyzed for saturated conductivity (Ksat) (Table 8). Ksat is a measured flux that is given in units of depth per time interval. These Ksat values fluctuate based on the permeability of the sample. Permeability can be lowered if there is compaction that occurs with the layer. This could be from the weight of sediments above or from the time of deposition. As this measurement is considered a completely saturated sample, the vadose zone flux would be lower than these values due to the capillary action of the pore water.

3.1.5 Alternate Nitrogen Transformation Pathways

Despite these nitrogen transformation processes potentially being microbial mediated DNRA, it is also possible that the process is entirely abiotic, or a combination of biotic and abiotic mechanisms involving sediment geochemistry. If this were the case, the results from the organic nitrogen and hot water extractable organic carbon (HWEOC) measurements, along with the future experimental plans, would only be telling part of the story. As is, the experiments conducted in this thesis show promising results. Some research claims that nitrogen will remain stable in an environment containing oxygen (Ottley et al., 1997). As this study takes place in the vadose zone, there is almost always oxygen present. However, at the high WFPS of the zones of interest, microbial processing in microsites is also a possibility.

Some studies have found that hydrogen sulfide and free sulfide ions could potentially serve as electron donors in DNRA and abiotically reduce nitrate to ammonium (Lu et al., 2013). Another potential abiotic pathway is iron catalyzed nitrate reduction to ammonium. In this pathway, with the presence of copper (II), nitrate becomes abiotically reduced to ammonium using iron as an electron donor (Ottley et al., 1997). The experiment by Ottley et al. (1997) was conducted at a pH of 8.0 and a temperature of 20°C. This reaction is inhibited when oxygen is present, due to oxygen competing with nitrate for the iron electrons though temperature of pore water in the study area would be lower than the experimental conditions. In the cores, the interval of interest has a WFPS of roughly 80% and 70-90% for DH-32 and DH-36, respectively. Although this soil is not fully saturated, this abiotic process can still occur because the soil does not need to be fully saturated for anerobic processes to occur.

This research reviews and summarize the gaps in literature of potential sources of ammonium in the vadose zone. In order to address this gap, investigations of trends in nitrogen use, root zone nitrogen and carbon, intermediate vadose zone nitrogen and carbon, water transport and dynamics, and alternate pathways were researched to create a more complete picture of the processes that are potentially occurring on ammonium content in the vadose zone.

3.2 Study Site Description

3.2.1 Central Platte Natural Resource District

This study is focused on two vadose zone core locations in the CPNRD from a project that included a total of 27 cores described in Chapter 2. These cores are locations DH-32 and DH-36.

3.2.2 Vadose Core Location DH-32

The DH-32 site is located in southern Hall County, south of Doniphan, NE. This site is under pivot irrigation with a depth to water of 83' in 2015 (Table 9). It is located in a Phase 2 groundwater management area. The surface soil consists of Hastings Silt Loam with a surface slope of 1-3%. This field is under a corn/soybean rotation. This location has a very sandy vadose zone profile with potentially high transport rates. Elevated pore water nitrate concentrations generally occur beneath the crop root zone, where the nitrate concentrations are also high. Total vadose zone nitrate-N storage decreased for the same interval in this location by 519 lbs-N/Acre, from 680 lbs-N/acre in 1996 to 161 lbs-N/acre in 2016 (Appendix 2). This site has an average volumetric moisture content of 0.224, which translates to an average water filled pore space (WFPS) of 57.6%. The average pH is 7.04 with the range between 5.92 and 7.38. The zone of interest for this experiment in this profile ranges from 63' to 65', with an emphasis on 63.2'.

Table 9. Core information for DH-32 and DH-36 sites.

	DH-32	DH-36
Depth to Water (ft)	83	124.5
Irrigation Method	Pivot	Pivot
Soil Taxonomy	Hastings Silt Loam	Hastings Silt Loam
Surface Slope (%)	1-3	1-3
Crop Type	Corn/Bean Rotation	Corn/Bean Rotation
Groundwater Control Phase	Phase 2	Phase 1
Longitude	40.738806	41.237247
Latitude	-97.533028	-99.491111

3.2.3 Vadose Core Location DH-36

Core DH-36 was collected in central Polk County, northeast of Osceola, NE. The site is under a corn and bean rotation (Table 9). In 2016, the depth to water at this location was 124.5’. It has been irrigated with pivots for 36 years, and uses no-till management. The producer reported that it receives an average of 180-200 lbs/acre of nitrogen on the corn, while years with soybeans do not receive N fertilizer application. In 1985, 1993, and 2008 the field received 10-12 tons/acre of poultry manure for fertilization. The surface soil is comprised of Hastings Silt Loam with a surface slope of 1-3%. Increased clay and silt in the top half of the profile slows transport, though pore water nitrate is relatively high in the lower half of the core, partly due to low water content at this zone. Overall, there was a drop of total nitrogen by 1,539 lbs-N/acre (55%) from 2,799 lbs-N/acre in 1996 to 1,260 lbs-N/acre in 2016 (Appendix 2). This site was previously cored, but the data from the previous study is missing (CPNRD, personal communication). This site has an average volumetric moisture content of 0.285, which translates to an average WFPS of 68.1%. The pH ranged from 5.31-7.27 with an average value of 6.58. The zone of interest for this experiment in this profile ranges from 34’ to 39’, with an emphasis on 36.5’ and 39’.

3.3 Methods

Sample extracts are analyzed using the Lachat Quikchem methods (Diamond, 2003; Knepel, 2012), results were converted to concentration per mass of soil. The results were graphed and analyzed using SigmaPlot 13.0 (Appendix 1). Based upon the results, two sites, DH-32 and DH-36 showed zones at depth where ammonium was higher than nitrate and these cores were selected for further analyses. The additional analyses selected was hot water extractable organic carbon (HWEOC), total organic carbon (TOC), carbon isotope composition of organic carbon (δ^{13}C-OC) signature and Total Kjeldahl Nitrogen (TKN).

HWEOC is measured by weighing out 5.0 grams of soil into a 50 mL centrifuge tube. 50 mL of water is then added to the sample. The sample is shaken vigorously for 30 seconds to mix the soil and water. The samples were then placed in a heated shaking water bath at 80°C for 90 minutes. Once this was completed, the samples were allowed to cool down to room temperature before being put in a centrifuge at 2500 rpm for 10 minutes, creating 2,935 relative centrifugal force, or g-force. The sample solution was then filtered into a clean vial using a 0.45 μm glass microfiber syringe filter. The samples are acidified with one drop of sulfuric acid for every 7 mL of sample, and then analyzed on an OI Corporation Model 1010 Carbon Analyzer.

TKN is the determination of the organic nitrogen content in wastewaters and soil, by converting organic materials to ammonium. This method utilizes the reagents copper sulfate as a catalyst, sulfuric acid, and potassium sulfate. If free ammonia is present, it will also be converted to ammonium. In this method, 0.5 grams of oven dried soil are put in a reaction flask. The reagents are added to the flask, along with 3 boiling chips per flask. These boiling chips help add surface area to the reaction and allow for a more even boil.

Reaction flasks are loaded onto the heating block and connected to the digestion block (Figure 21). Samples were gradually heated to four different temperatures stepwise to allow for a slow boil. This slow boil keeps the samples from boiling into the vacuum manifold and contaminating all of the samples. Once the samples were completed on the heating block, they were allowed to cool slightly. Samples were rinsed with distilled de-ionized water (DDI) into 50 mL centrifuge tubes to a volume of 25mL. The centrifuge tubes were allowed to cool to room temperature and then centrifuged at 2500 rpm for ten minutes. After the samples had been centrifuged, they were taken out of the centrifuge tube with a transfer pipette and analyzed using Seal Analytical AQ2 method (Seal Analytical, 2012). Similar to the Lachat, results were converted to account for the weight of soil sample used. Graphical analysis was conducted with SigmaPlot 13.0.

TOC and ^{13}C-OC samples were prepped using an acid fumigation method to remove carbonate carbon from samples (Johnson et al., 2018). This method calls for 200 mg of finely ground sample, but as the method is for sedimentary rock and the samples being analyzed were high carbon soil samples, samples were weighed out to approximately 50 µg. Samples were weighed out into a small tin capsule. Capsules were left open in a sealed desiccator to fumigate with an open container of concentrated hydrochloric acid. Samples were fumigated for 6 hours. After this fumigation process, the tin capsules were carefully closed up and placed in a Carlo Erba NA-1500 elemental analyzer coupled to a GV2003 isotope ratio mass spectrometer (EA-IRMS), which measured both δ^{13}C-OC and TOC by combustion. Calibration for both carbon content (%) and isotope composition (‰) used standards of known isotope composition (USGS 40,-26.39‰;USGS41 +37.63‰; IAEACH6, -10.45‰; and a working standard WSL Sucrose, -11.8‰).

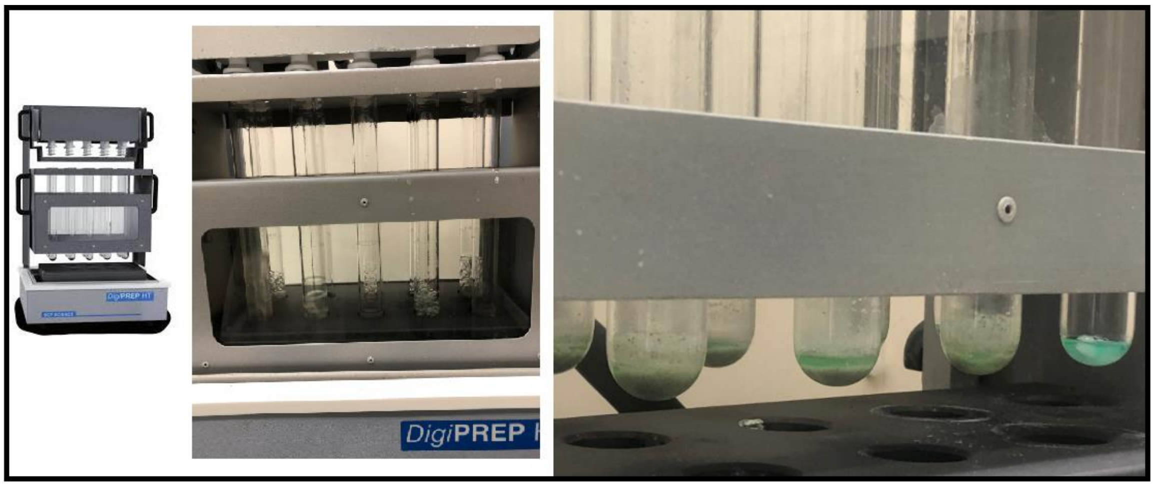


Figure 21. (Left to right) The heating block used with the TKN manifold; TKN samples being boiled down; and the resulting TKN extract.

3.4 Results and Discussion

3.4.1 Results for DH-32

Full tabulated results of soil physical and chemical data for DH-32 can be found in Appendix 1 and Appendix 4. For the current experiment, DH-32 has relatively low nitrate-N and ammonium-N concentrations compared to other locations throughout the CPNRD (Appendix 2). At the surface of the profile, there are higher nitrate-N concentrations than there are further into the vadose zone. This concentration drops off as depth increases from the root zone, showing that most of nitrate is utilized by plants or other removal mechanisms (Figure 23). Further down in the profile there is a single spike in nitrate-N at 63.2'. The same pattern is true for ammonium-N in both the root zone and intermediate vadose zone. The highest concentrations of both nitrate-N and ammonium-N are both found at the uppermost sample, equaling 2.25 µg/g and 5.09 µg/g, respectively (Appendix 2). At the depth of 63.2', ammonium-N has the second highest concentration from the entire profile of 3.56 µg/g.

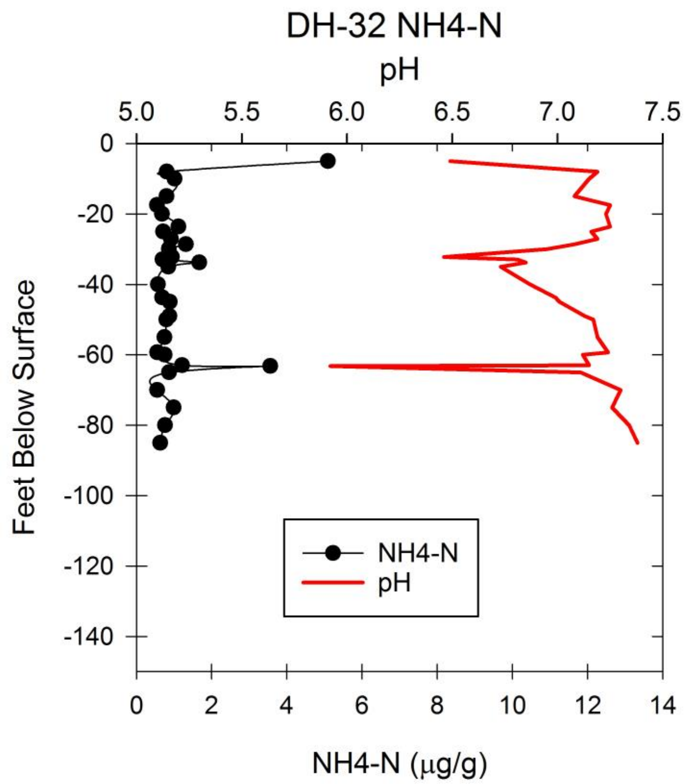


Figure 22. This graph shows the relationship between ammonium and pH in the vadose zone at site DH-32.

Organic values followed the same trend as nitrate-N and ammonium-N by having the largest concentration in the uppermost sample, but followed nitrate-N more closely in the top 30' of the profile. Similar to nitrate-N and ammonium-N, a large spike in organic nitrogen concentration equaling 686 µg/g can be seen at 63.2' (Figure 22). HWEOC has the highest concentration at a depth of 27.1', but following the nitrogen trend, has another high concentration at 63.2'. TOC content follows the trend of HWEOC, with a noticeable peak at 63.2'. At this depth, there is also an increase in $\delta^{13}C$ at -22.2‰, showing a value similar to that found for C_4 plants. A ratio of HWEOC:TOC in this sample also show a very small ratio of the carbon present is dissolved.

In this depth of interest, the sediment texture is a clay loam. Due to the clay content, this sample has gravimetric and volumetric moisture contents higher than the averages, with values of 0.156 and 0.224, respectively (Figure 23, Table 10). The porosity calculation shows that a total of 44.8% of the volume is pore space, which is slightly higher than the profile average of 42%. However, this sample has a much higher WFPS of 78.4%. In this sample above the zone of interest at 63' the pH is 7.15, then drops to 5.92 at 63.2', before rising back to 7.11 at 65'.

Table 10. The average, minimum, and maximum values of soil properties for core DH-32 along with the values in the sample of interest, 63.2'. There were 28 samples for the core DH-32 (n=28).

	Average	**Minimum**	**Maximum**	**63.2'**
NO3-N (ug/g)	0.64	0.13	2.25	0.99
NH4-N (ug/g)	1.08	0.55	5.09	3.56
TKN (ug/g)	248	41	1395	689
HWEOC (ug/g)	70	31	179	102
TOC	1,549	220	8,330	5,270
δ^{13}C-OC	-29.1	-34.6	18.0	-22.2
ρb (g/ml)	1.53	1.09	2.26	1.46
Ɵg	0.16	0.04	0.28	0.240
θv	0.22	0.07	0.38	0.351
Porosity	0.42	0.15	0.59	0.448
WFPS	0.53	0.18	1.00	0.784
pH Analysis	7.04	5.92	7.38	5.92

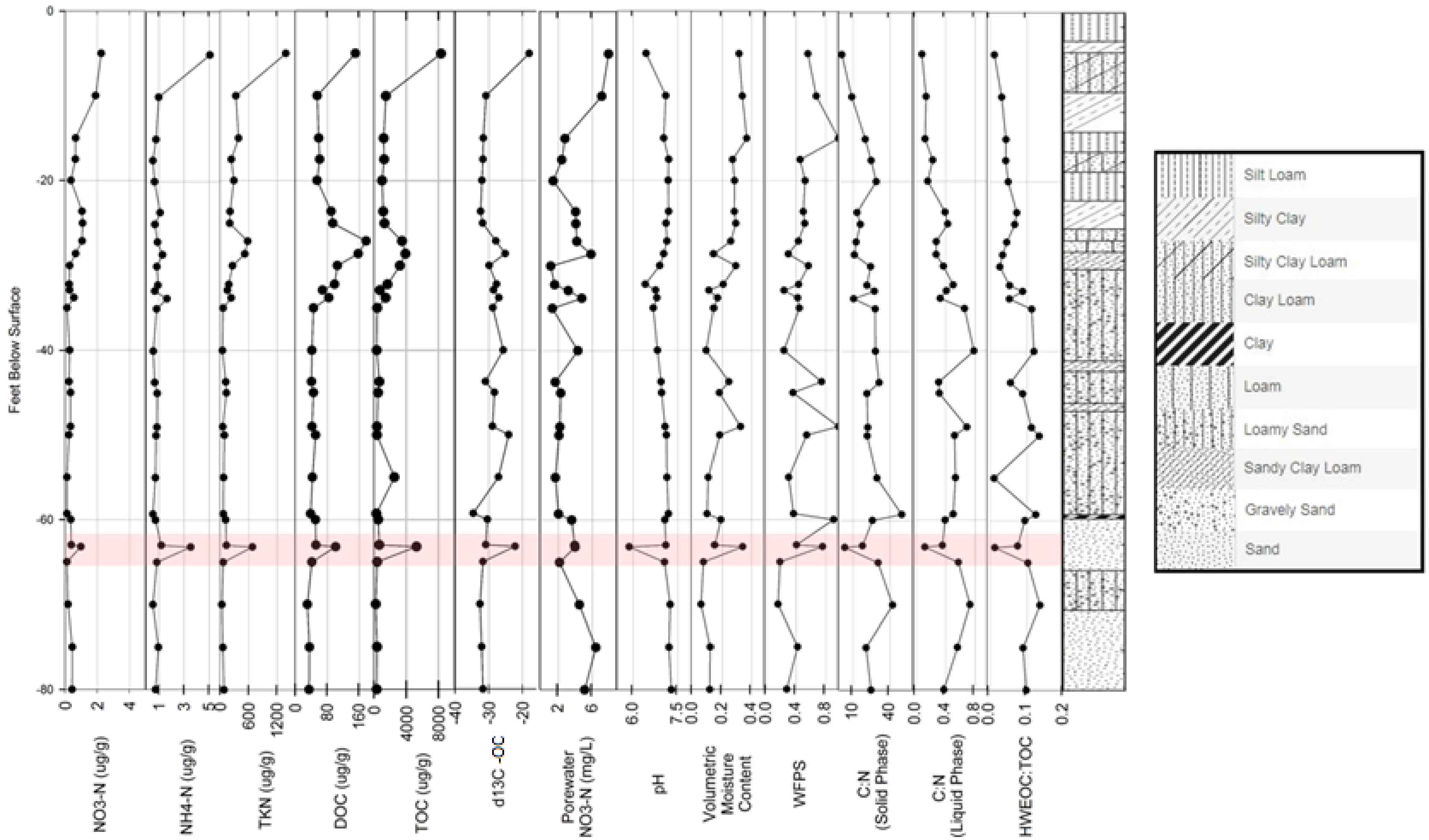


Figure 23. DH-32 graphed results with potential N transformation zone highlighted in red.

3.4.2 Results for DH-36

Full tabulated results of soil physical and chemical data for DH-36 can be found in Appendix 1. For the current experiment, DH-36 had higher nitrate-N concentrations than DH-32, but relatively low nitrate-N and ammonium-N concentrations compared to other locations throughout the CPNRD (Appendix 2). Similar to most vadose zone profiles, there is a peak of nitrate-N at the surface samples contained in the root zone. As the profile moves out of the root zone and into the intermediate vadose zone, there is a decrease in nitrate concentrations before slightly increasing to the zone of interest at 36.5' (Figure 25). Further down the profile, nitrate-N concentrations fluctuate with little similarity between other chemical properties. The average nitrate-N concentration for the profile is 2.76 µg/g, with a minimum concentration of 0.26 µg/g at 36.5' and a maximum of 7.08 at 96.5' (Table 11).

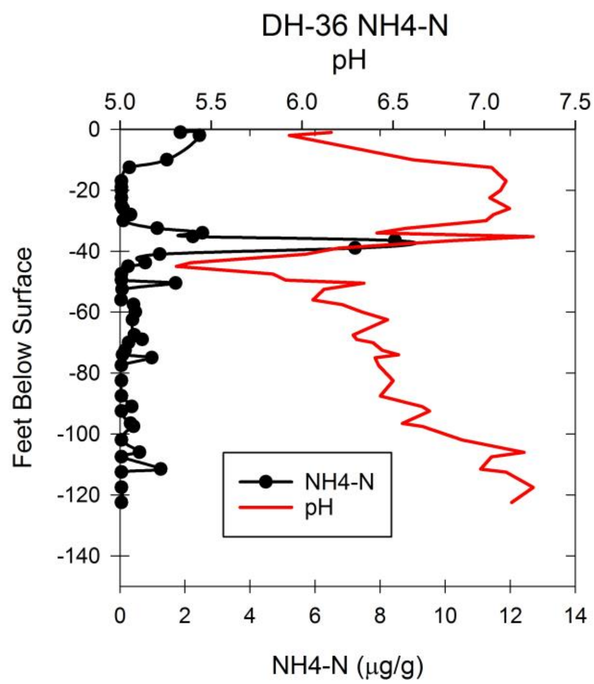


Figure 24. This graph shows the relationship between ammonium and pH at site DH-36.

Ammonium-N in the root zone at DH-36 starts at a low concentration in the root zone and increases to a high concentration of 8.46 µg/g in the zone of interest. This zone contains the two highest ammonium-N concentrations in the profile, 8.46 µg/g at 36.5' and 7.23 µg/g at 39'. Beyond the zone of interest, there are minimal ammonium-N concentrations. Organic nitrogen concentrations follow the same pattern as ammonium-N in this vadose zone profile.

The two highest concentrations are found in the zone of interest with little to no organic nitrogen found below this interval. HWEOC concentrations virtually mimic the organic nitrogen concentrations, with the expected exception of a higher concentration of HWEOC in the root zone. TOC followed the same trend as HWEOC throughout the profile, with a higher concentration at the surface, then little carbon content until the large spike in the zone of interest at 36.5', before dropping back to low concentrations (Figure 25). Similar to the samples in the zone of interest at 63.2' at site DH-32, the samples in the zone of interest at 36.5' at site DH-36 has a low ratio of HWEOC:TOC.

The sediment texture in the zone of interest is loam. This sample also has the highest gravimetric and volumetric moisture content, at 0.388 and 0.484, respectively. The porosity of this sample is also higher than average and close to the maximum value found in the profile. The WFPS is 91.4%, so it is nearly completely saturated. The pH in this sample is 6.83. The entire zone of interest for DH-36 is a steady decline in pH.

Table 11. The average, minimum, and maximum values of soil properties from core DH-36 along with the sample of interest, 36.5'. There were 47 samples at site DH-36 (n=47).

	Average	Minimum	Maximum	36.5'
NO_3-N (µg/g)	2.76	0.26	7.08	0.26
NH_4-N (µg/g)	0.82	0.04	8.46	8.46
TKN (µg/g)	232	1.85	2919	1302
HWEOC (µg/g)	53.4	21.7	325	204
TOC	3,038	220	48,200	25,600
δ^{13}C-OC	-25.1	-32.0	-10.8	-27.4
Θg	0.19	0.02	0.39	0.39
Θv	0.29	0.03	0.48	0.48
Porosity	0.43	0.21	0.57	0.53
WFPS	0.68	0.07	1.00	0.91
pH Analysis	6.57	5.31	7.27	6.83
ρb (g/ml)	1.52	1.15	2.10	1.25

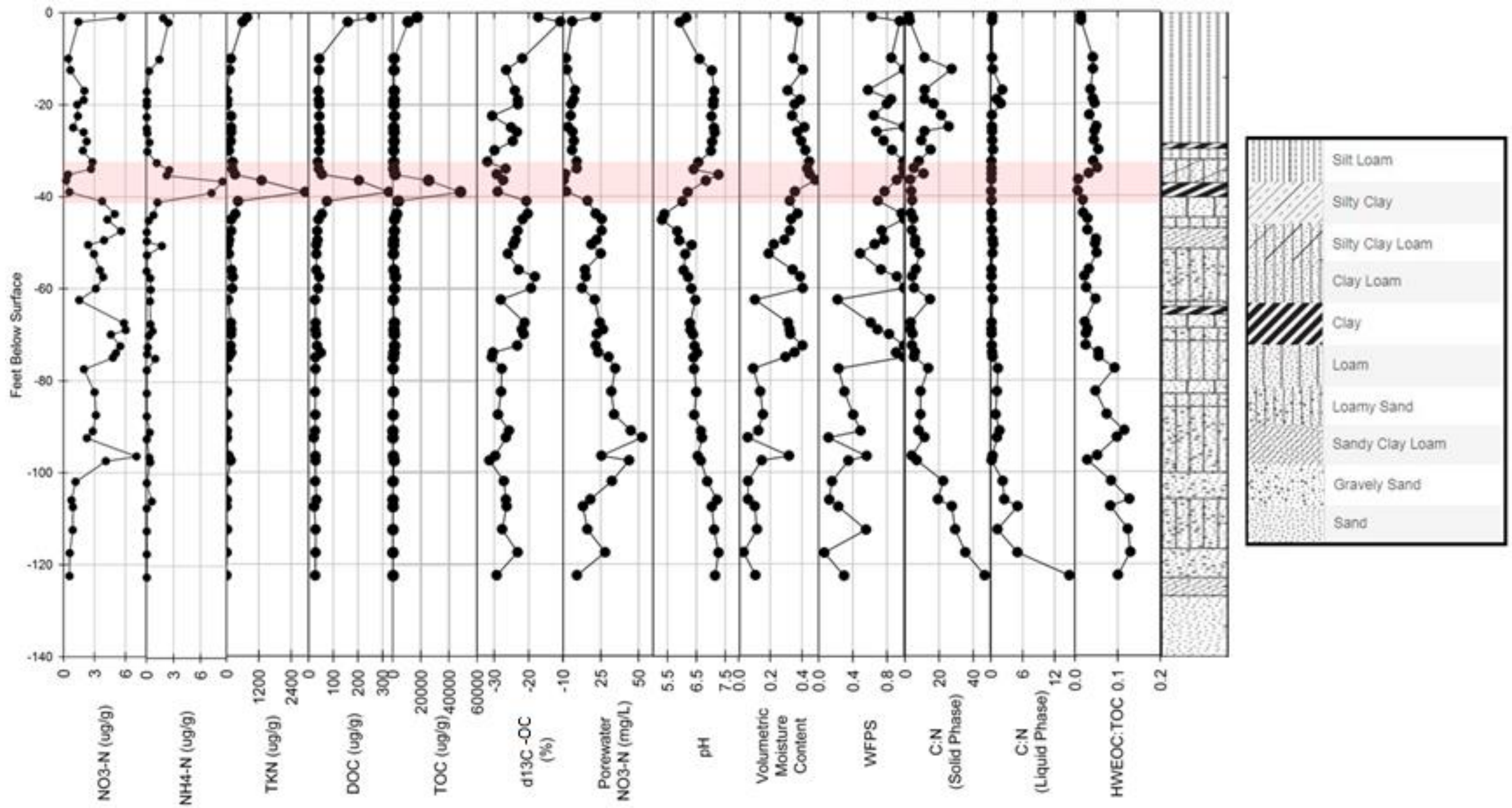


Figure 25. DH-36 graphed results with potential N transformation zone highlighted in red.

3.4.3 Discussion

These measurements show some interesting patterns within the zone of interest, at 63.5' at site DH-32 and at 36.2' at site DH-36. There are multiple pathways that convert nitrate to ammonium (Figure 26). The samples examined in this study both show similar patterns and appear to follow the criteria for DNRA more closely than for iron catalyzed nitrate reduction to ammonium and for sulfur driven nitrate reduction.

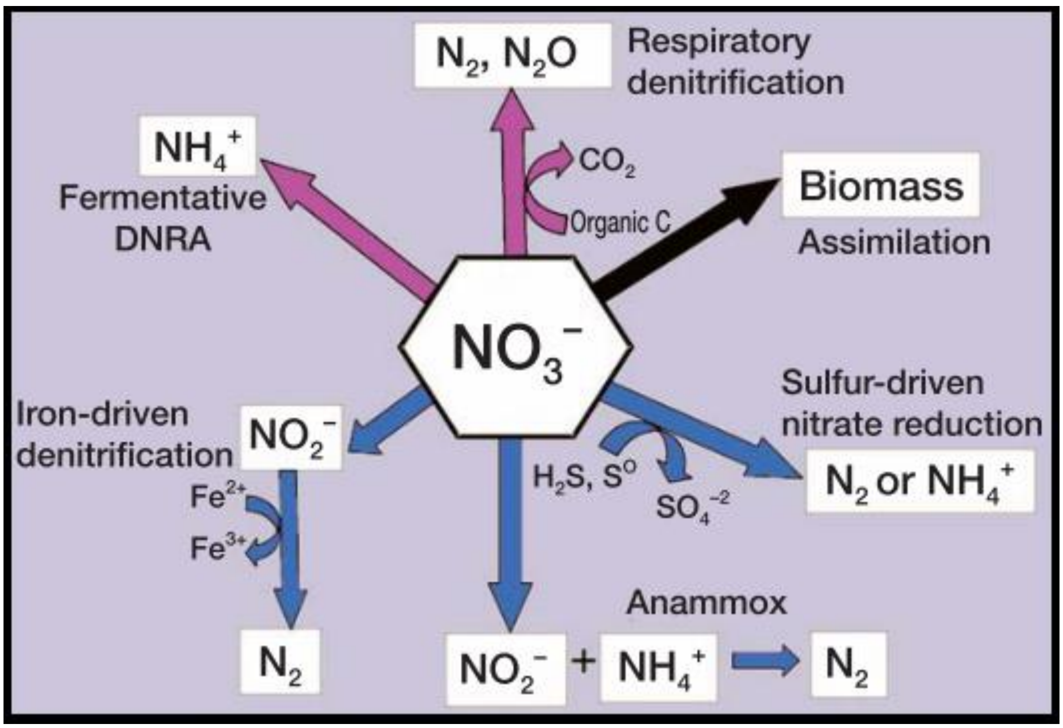


Figure 26. A figure from Burgin & Hamilton (2007) showing the different transformation pathways for nitrate.

The pathway of iron catalyzed nitrate reduction to ammonium is generally considered to be a pathway found in groundwater (Ottley et al., 1997). It is an abiotic pathway that takes place best at a pH of 4. Experimental conditions in Ottley et al. (1997) used a pH range of 7-8.5 at 20°C. These experimental parameters are closer to natural groundwater conditions, but the samples in this study are from the vadose zone where pH varies more than groundwater. This reaction requires anoxic conditions with the presence of reduced iron and may occur in the low carbon environment typical of groundwater ecosystems. This does not hold true for either location, where at 63.5' at site DH-32 and at 36.2' at site DH-36, there are spikes in both HWEOC and TOC. This reaction is feasible, but it requires a metal catalyst, such as copper, tin, or silver (Ottley et al., 1997). This pathway occurs along the time scale of months to years.

The range of optimum pH value of 4 and the experimental pH range used by Ottley et al. (1997) lower than what is found in the samples, as well as the timescale of this reaction. At site DH-32, the sample in the zone of interest has a pH close to 6, so as pH is reported in a log scale, the sample has 100x more H^+ ions. Similarly, at site DH-36, the sample in the zone of interest has a pH close to 7, which is 1000x higher H^+ ions. However, as this reaction takes place in a low carbon environment, the high HWEOC concentration in this zone also hints at a different pathway.

Another pathway for nitrate conversion to ammonium requires reduced sulfur (S^{-2} or S^0). This method is a biotic pathway that couples nitrate reduction to oxidation of reduced sulfur forms and elemental sulfur (Burgin & Hamilton, 2007). This can be done by a variety of bacteria, many with internal storage structures to sequester nitrate and sulfur within them (Burgin & Hamilton, 2007). This pathway is possible, but as this thesis did not investigate sulfur content, it cannot be concluded if this is a potential pathway. However, sulfur is known to be converted to sulfuric acid in soils and lower the pH (Longstroth, 2012). This is consistent with site DH-32, where the zone of interest has a large drop in pH for the sample at 63.2'. That means that this could potentially be part of the pathway, but without analyzing samples for sulfide, it cannot be definitive.

One more potential pathway in the samples at 63.5’ at site DH-32 and at 36.2’ at site DH-36, could be microbial decomposition of a carbon rich layer. As stated, this carbon content could have been in place at the time that the layer was buried. This would lead to high TOC content, which both samples at 63.5’ at site DH-32 and at 36.2’ at site DH-36 have. As microbial decomposition occurs, microbes will respirate and release carbon dioxide, which will react with pore water and create carbonic acid. This is a potential pathway at 63.5’ at site DH-32, where there is a carbon deposit, a low pH, higher moisture content, and a spike in $\delta^{13}C$. This spike in $\delta^{13}C$ could be an enrichment from microbes discriminating against the heavier ^{13}C isotope. At site DH-36 at 36.2’, there is a spike in HWEOC, TOC, and TKN concentrations, but $\delta^{13}C$ is a slight increase compared to the samples above in the profile, so there is little enrichment from potential decomposition.

Finally, DNRA is a biotic pathway for nitrate to convert to ammonium. Little is known about the controls in the system or what management practices effect DNRA the most (Putz et al., 2018). One factor that has been widely agreed upon is that DNRA takes place in a high carbon content environment with labile carbon being the main driving factor (Fazzolari et al., 1998; Friedl et al., 2018; Putz et al., 2018). Systems with high carbon conservation management practices, such as ley farming, correlate with higher DNRA than soils that are planted solely with grains (Putz et al., 2018). One study also claimed that DNRA is less sensitive than denitrification to oxygen inhibition (Fazzolari et al., 1998), meaning that it is possible for DNRA to occur in a sediment that is not fully saturated. Another study claimed that redox potential might also play a high factor in DNRA (Friedl et al., 2018), but it was not definitive. The process claimed by Friedl et al.

(2018) essentially stated that a soil that has high labile carbon availability drives heterotrophic respiration, reducing soil redox potential, and shifting consumption from denitrification to DNRA. Experimental results from Friedl et al. (2018) show DNRA versus nitrification rates at different WFPS (Figure 27).

Both DH-32 and DH-36 have high organic nitrogen concentrations in the zone of interest. These concentrations show that there is a lot of organic nitrogen present that could likely be derived from microbes and microbial by-products, or potentially either produced in place or geogenic. As carbon is the main driver in microbial respiration according to all of the cited literature, the HWEOC content is critical for the comparison of pathways. The HWEOC content in both DH-32 and DH-36 is elevated compared to the intervals both above and below. The WFPS is also high, which when comparing to experimental results in the literature (Friedl et al., 2018), a WFPS of 78.4% in a clay loam at DH-32 shows that the ratio of DNRA to nitrification should be roughly 50%, which has a higher proportion of nitrate going to denitrification than at lower WFPS. At DH-36, the soil is a loam with a WFPS of 91.4%, which would have over 75% of the microbial activity being DNRA.

If the pathway is truly fermentation, as some researchers claim it could be, the samples would need a high carbon content for the reaction to occur. As soils become saturated, they become anaerobic, which is necessary for fermentation to take place. Both samples at 63.5’ at site DH-32 and at 36.2’ at site DH-36 have high WFPS. Fermentation reactions produce acids, dropping the pH, which is another potential cause of the drop in pH at 63.5’ at site DH-32. As water is transported down the profile, WFPS will fluctuate, and potentially turn the process aerobic and away from fermentation. This could allow for nitrification to occur, converting the ammonium back to nitrate. It is most likely that out of the processes named, DNRA is the main pathway converting nitrate to ammonium. Further experimental data can help solidify this conclusion, such as a microbial assay.

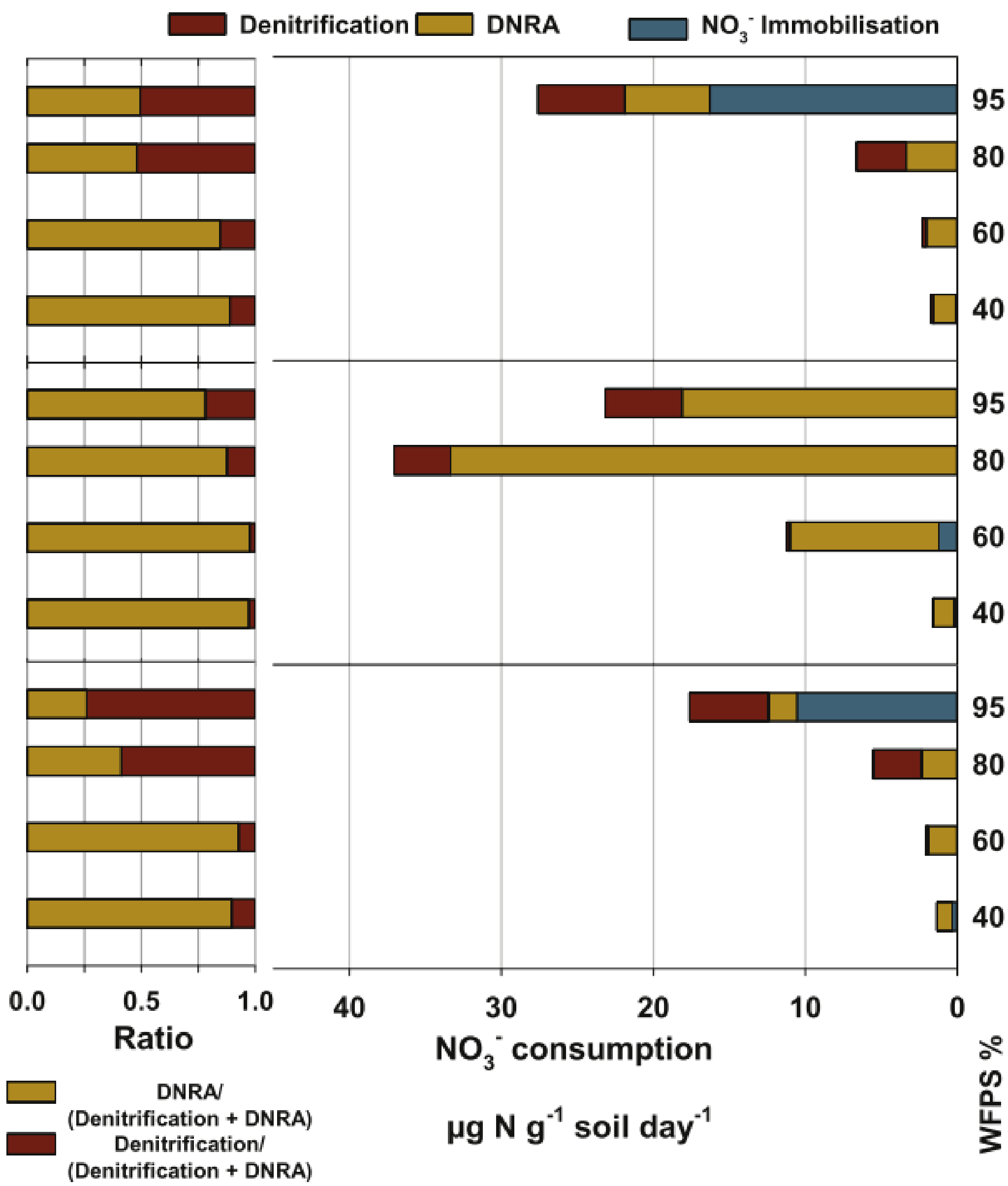


Figure 27. Friedl et al. (2018) shows their experimental results that compare water filled pore space with rates of dissimilatory nitrate reduction to ammonium and denitrification. The top series is for a clay soil, the middle series is for a loam soil, and the bottom series is for a sandy clay loam soil.

3.4.4 Limitations

Experimental limitations include evaluation of the initial processing of the soil cores. When the soil cores were initially set out to thaw, there is a potential that some of the carbon content could have been lost as carbon dioxide (Holden & Fierer, 2005) or nitrogen lost as either nitrogen gas, nitric oxide, or nitrous oxide (Holden & Fierer, 2005; Wang et al., 2017). Along with the processing, the HWEOC method utilizes a hot water bath, which could potentially denature proteins, resulting in artificially high measurements.

3.4.5 Future Work

As DNRA is not thoroughly understood in the subsurface environments, there are considerable avenues for future work. This present experiment is not exempt. Future work for this project could involve nitrogen isotopes and gene extraction for a microbial assay.

Nitrogen isotope analysis to determine changes in natural abundance as a function of depth would provide insights into nitrogen cycling and potentially the source of the nitrogen at various depths. Nucleic acid extraction from sediments to detect specific N transformations genes would also provide a clearer understanding of microbial processes in the vadose zone. The final experiments that could be conducted on these samples to determine if there are alternate pathways at work are sulfur, redox potential, and iron content analysis. This would help determine if the other two pathways discussed are playing a factor in nitrate transformations.

3.5 Summary and Conclusion

There are multiple processes that act on nitrogen and carbon in the vadose zone. Considerable research on nitrogen cycling in soil environments focuses on the root zone with little attention paid to transformations in the deeper soils. As the nitrogen cycles in the root zone, most ammonium and nitrate are taken up by crops and used to create biomass. These crops go through their growth cycle and are harvested, leaving plant material behind to be decomposed and add to the soil organic matter in the root zone. As nitrate is a highly soluble anion, it will not bind with clay minerals and will leach freely with soil water. Inversely, ammonium, a cation, will mostly bind to clay minerals and not be readily transported with soil water.

As carbon is further decomposed into a soluble fraction, it joins nitrate and is transported past the root zone with percolating soil water. Upon entering the intermediate vadose zone, it is often assumed that there is little or no further conversions on these dissolved compounds until it reaches the groundwater. However, there are different biogeochemical transformations that can utilize and convert these compounds.

Noticeably large concentrations of ammonium-N in the deep vadose zone sparked investigation into its origin. As ammonium is expected to be bound, percolating water should have little to no effect on transport. However, in the same sample as the noticeable ammonium peak, there were patterns in the nitrate-N concentrations, instigating a literature review.

There are multiple pathways that can convert nitrate to ammonium, but the data in this thesis supports DNRA for the sites that were investigated. These alternate pathways include iron catalyzed nitrate reduction to ammonium, an abiotic pathway generally occurring in the groundwater; nitrate conversion to ammonium using sulfide ions, which is a coupled biotic and abiotic pathway; and DNRA, which is a solely biotic transformation.

Experimental data shows that in these zones of interest, there are high ammonium-N, organic nitrogen, TOC, and HWEOC concentrations. In DH-32, there is also a small spike in nitrate-N concentrations, drop in pH, and $\delta^{13}C$ enrichment hinting that there could be another pathway other than DNRA. These data suggest that the pathway is microbial decomposition. In DH-36, there is a drop in nitrate-N concentrations in the zone of interest and a slight negative gradient in pH values in the zone of interest. There does not appear to be any ^{13}C loading from microbial decomposition of carbon. Future analyses can help rule out alternate pathways and continue to build on the needed knowledge of nitrogen storage and transformations in the vadose zone.

The hypothesis for this thesis is that agricultural production land that has been switched from gravity to pivot irrigation will slow solute movement and allow for more microbial processing to occur in the vadose zone, converting nitrate to ammonium. This hypothesis is rejected for site DH-32, but supported by site DH-36. This research began by investigating nitrate storage in the vadose zone and finding concentrations in the deep vadose zone. The current literature focuses primarily on wastewater effluents when investigating ammonium in the vadose zone. This research starts a new pathway of analyzing deep soil and sediment samples to find the potential source of the ammonium concentrations in the deep vadose zone. A better understanding of the processes and what analyses can be conducted will help further this research.

Literature Cited

Adelman, D. D., Schroeder, W. J., Smaus, R. J., Wallin, G. P., Adelman, D. D., & Schroeder, W. J. (1985). Overview of Nitrate in Nebraska ' s Ground Water. *Transactions of the Nebraska Academy of Sciences and Affiliated Societies*, *Paper 220*, 75–81.

Bobier, M. W., Frank, K. D., & Spalding, R. F. (1993). Nitrate-N movement in a fine textured vadose zone. *Journal of Soil and Water Conservation*, *48*(4), 350–354. https://doi.org/10.1016/j.forsciint.2004.04.059

Böhlke, J. K., Smith, R. L., & Miller, D. N. (2006). Ammonium transport and reaction in contaminated groundwater: Application of isotope tracers and isotope fractionation studies. *Water Resources Research*, *42*(5), 1–19. https://doi.org/10.1029/2005WR004349

Boström, B., Comstedt, D., & Ekblad, A. (2007). Isotope fractionation and 13C enrichment in soil profiles during the decomposition of soil organic matter. *Oecologia*, *153*(1), 89–98. https://doi.org/10.1007/s00442-007-0700-8

Bouwman, A. F., Boumans, L. J. M., & Batjes, N. H. (2002). Estimation of global NH 3 volatilization loss from synthetic fertilizers and animal manure applied to arable lands and grasslands . *Global Biogeochemical Cycles*, *16*(2), 8-1-8–14. https://doi.org/10.1029/2000gb001389

Boyce, J. S., Muir, J., Edwards, A. P., Seim, E. C., & Olson, R. A. (1976). Geologic Nitrogen in Pleistocene Loess of Nebraska. *Journal of Environment Quality CN - 0000*, *5*(1), 93–96.

Bremner, J. M. (1965). Inorganic Forms of Nitrogen. In *Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties* (Issue 2, pp. 1179–1237). American Society of Agronomy, Soil Science Society of America.

Burgin, A. J., & Hamilton, S. K. (2007). Have we overemphasized the role of denitrification in aquatic ecosystems? A review of nitrate removal pathways. *Frontiers in Ecology and the Environment*, *5*(2), 89–96. https://doi.org/10.1890/1540-9295(2007)5[89:HWOTRO]2.0.CO;2

Burow, K. R., Nolan, B. T., Rupert, M. G., & Dubrovsky, N. M. (2010). Nitrate in groundwater of the United States, 1991 - 2003. *Environmental Science & Technology*, *44*(13), 4988–4997. https://doi.org/10.1021/es100546y

Buss, S. R., Herbert, A. W., Morgan, P., Thornton, S. F., & Smith, J. W. N. (2004). A review of ammonium attenuation in soil and groundwater. *Quarterly Journal of Engineering Geology and Hydrogeology*, *37*(4), 347–359. https://doi.org/10.1144/1470-9236/04-005

Cannavo, P., Richaume, A., & Lafolie, F. (2004). Fate of nitrogen and carbon in the vadose zone: In situ and laboratory measurements of seasonal variations in aerobic respiratory and denitrifying activities. *Soil Biology and Biochemistry*, *36*(3), 463–478. https://doi.org/10.1016/j.soilbio.2003.10.023

Cao, P., Lu, C., & Yu, Z. (2018). Historical nitrogen fertilizer use in agricultural ecosystems of the contiguous United States during 1850-2015: Application rate, timing, and fertilizer types. *Earth System Science Data*, *10*(2), 969–984. https://doi.org/10.5194/essd-10-969-2018

Cather, S. M., Chapin, C. E., & Kelley, S. A. (2012). Diachronous episodes of Cenozoic erosion in southwestern North America and their relationship to surface uplift, paleoclimate, paleodrainage, and paleoaltimetry. *Geosphere*, *8*(6), 1177–1206. https://doi.org/10.1130/GES00801.1

Denk, T. R. A., Mohn, J., Decock, C., Lewicka-Szczebak, D., Harris, E., Butterbach-Bahl, K., Kiese, R., & Wolf, B. (2016). The nitrogen cycle: A review of isotope effects and isotope modeling approaches. *Soil Biology and Biochemistry*. https://doi.org/10.1016/j.foodchem.2016.07.073

Di, H. J., & Cameron, K. C. (2002). Nitrate leaching in temperate agroecosystems: Sources, factors and mitigating strategies. *Nutrient Cycling in Agroecosystems*, *64*(3), 237–256. https://doi.org/10.1023/A:1021471531188

Diamond, D. (2003). *Determination of Ammonia in 1.0M Potassium Chloride Soil Extracts by Flow Injection Analysis*.

Exner, M. E., Hirsh, A. J., & Spalding, R. F. (2014). Nebraska's groundwater legacy: Nitrate contamination beneath irrigated cropland. *Water Resources Research*, *1*, 4840–4847. https://doi.org/10.1002/2015WR017273.Received

Fazzolari, É., Nicolardot, B., & Germon, J. C. (1998). Simultaneous effects of increasing levels of glucose and oxygen partial pressures on denitrification and dissimilatory nitrate reduction to ammonium in repacked soil cores. *European Journal of Soil Biology*, *34*(1), 47–52. https://doi.org/10.1016/S1164-5563(99)80006-5

Ferguson, R. B. (2015). Groundwater Quality and Nitrogen Use Efficiency in Nebraska's Central Platte River Valley. *Journal of Environment Quality*, *44*(2), 449. https://doi.org/10.2134/jeq2014.02.0085

Friedl, J., De Rosa, D., Rowlings, D. W., Grace, P. R., Müller, C., & Scheer, C. (2018). Dissimilatory nitrate reduction to ammonium (DNRA), not denitrification dominates nitrate reduction in subtropical pasture soils upon rewetting. *Soil Biology and Biochemistry*, *125*(July), 340–349. https://doi.org/10.1016/j.soilbio.2018.07.024

Fronczyk, J., Sieczka, A., Lech, M., Radziemska, M., & Lechowicz, Z. (2016). Transport of nitrogen compounds through subsoils in agricultural areas: Column tests. *Polish Journal of Environmental Studies*, *25*(4), 1505–1514. https://doi.org/10.15244/pjoes/62340

Garg, K. K., Jha, M. K., & Kar, S. (2005). Field investigation of water movement and nitrate transport under perched water table conditions. *Biosystems Engineering*, *92*(1), 69–84. https://doi.org/10.1016/j.biosystemseng.2005.05.016

Gurdak, J. J., & Qi, S. L. (2012). Vulnerability of recently recharged groundwater in principle aquifers of the United States to nitrate contamination. *Environmental Science and Technology*, *46*(11), 6004–6012. https://doi.org/10.1021/es300688b

Heil, J., Vereecken, H., & Brüggemann, N. (2016). A review of chemical reactions of nitrification intermediates and their role in nitrogen cycling and nitrogen trace gas formation in soil. *European Journal of Soil Science*, *67*(1), 23–39. https://doi.org/10.1111/ejss.12306

Hergert, G. W., & Shapiro, C. A. (2015). Irrigation and Nitrogen Management. *University of Nebraska–Lincoln Extension*.

Holden, P. A., & Fierer, N. (2005). Microbial Processes in the Vadose Zone. *Vadose Zone Journal*, *4*(1), 1. https://doi.org/10.2136/vzj2005.0001

Holloway, J. M., Dahlgreen, R. A., & Casey, W. H. (1998). Contributions of bedrock nitrogen to high nitrate concentrations in stream water. *Nature*, *395*(October), 785–788.

Holloway, J. M., & Dahlgren, R. A. (2002). Nitrogen in rock: Occurrences and biogeochemical implications. *Global Biogeochemical Cycles*, *16*(4), 65-1-65–17. https://doi.org/10.1029/2002GB001862

Houlton, B. Z., Morford, S. L., & Dahlgren, R. A. (2018). Convergent evidence for widespread rock nitrogen sources in Earth ' s surface environment. *Science*, *360*(6384), 58–62.

Jardine, P. M., Mayes, M. A., Mulholland, P. J., Hanson, P. J., Tarver, J. R., Luxmoore, R. J., McCarthy, J. F., & Wilson, G. V. (2006). Vadose Zone Flow and Transport of Dissolved Organic Carbon at Multiple Scales in Humid Regimes. *Vadose Zone Journal*, *5*(1), 140. https://doi.org/10.2136/vzj2005.0036

Johnson, C. A., Stricker, C. A., Gulbranses, C. A., & Emmons, M. P. (2018). Determination of d13C, d15N, or d34S by Isotope-Ratio-Monitoring Mass Spectrometry Using an Elemental Analyzer. In *Laboratory Analysis* (1st ed.). U.S. Department of the Interior, U.S. Geological Survey.

Jones, D. L., Magthab, E. A., Gleeson, D. B., Hill, P. W., Sánchez-Rodríguez, A. R., Roberts, P., Ge, T., & Murphy, D. V. (2018). Microbial competition for nitrogen and carbon is as intense in the subsoil as in the topsoil. *Soil Biology and Biochemistry*, *117*(October 2017), 72–82. https://doi.org/10.1016/j.soilbio.2017.10.024

Kadyampakeni, D. M., Nkedi-kizza, P., Leiva, J. A., Muwamba, A., Fletcher, E., & Morgan, K. T. (2018). *Ammonium and nitrate transport during saturated and* *unsaturated water flow through sandy soils*. 198–210. https://doi.org/10.1002/jpln.201700405

Kaiser, K., & Kalbitz, K. (2012). Cycling downwards - dissolved organic matter in soils. *Soil Biology and Biochemistry*, *52*, 29–32. https://doi.org/10.1016/j.soilbio.2012.04.002

Keesstra, S. D., Geissen, V., Mosse, K., Piiranen, S., Scudiero, E., Leistra, M., & van Schaik, L. (2012). Soil as a filter for groundwater quality. *Current Opinion in Environmental Sustainability*, *4*(5), 507–516. https://doi.org/10.1016/j.cosust.2012.10.007

Kettler, T. A., Doran, J. W., & Gilbert, T. L. (2001). Simplified Method for Soil Particle-Size Determination to Accompany Soil-Quality Analyses. *Soil Science Society of America Journal*, *65*(3), 849–852. https://doi.org/10.2136/sssaj2001.653849x

Knepel, K. (2012). *Determination of Nitrate in 2M KCl Soil Extracts by Flow Injection Analysis*.

Liu, X., Sun, S., Ji, P., & Simunek, J. (2013). Evaluation of historical nitrate sources in groundwater and impact of current irrigation practices on groundwater quality. *Hydrological Sciences Journal-Journal Des Sciences Hydrologiques*, *58*(1), 198–212. https://doi.org/10.1080/02626667.2012.745937

Longstroth, M. (2012). Lowering the Soil pH with Sulfur. In *MSU Extension*. http://blueberries.msu.edu/uploads/files/Lowering_Soil_pH_with_Sulfur.pdf

Loveland, P., & Webb, J. (2003). Is there a critical level of organic matter in the agricultural soils of temperate regions: A review. In *Soil and Tillage Research* (Vol. 70, Issue 1, pp. 1–18). https://doi.org/10.1016/S0167-1987(02)00139-3

Lu, W. W., Zhang, H. L., & Shi, W. M. (2013). Dissimilatory nitrate reduction to ammonium in an anaerobic agricultural soil as affected by glucose and free sulfide. *European Journal of Soil Biology*, *58*(3), 98–104. https://doi.org/10.1016/j.ejsobi.2013.07.003

Marschner, B., Brodowski, S., Dreves, A., Gleixner, G., Gude, A., Grootes, P. M., Hamer, U., Heim, A., Jandl, G., Ji, R., Kaiser, K., Kalbitz, K., Kramer, C., Leinweber, P., Rethemeyer, J., Schäffer, A., Schmidt, M. W. I., Schwark, L., & Wiesenberg, G. L. B. (2008). How relevant is recalcitrance for the stabilization of organic matter in soils? *Journal of Plant Nutrition and Soil Science*, *171*(1), 91–110. https://doi.org/10.1002/jpln.200700049

Mekala, C., & Nambi, I. M. (2017). Understanding the hydrologic control of N cycle: Effect of water filled pore space on heterotrophic nitrification, denitrification and dissimilatory nitrate reduction to ammonium mechanisms in unsaturated soils. *Journal of Contaminant Hydrology*, *202*(April), 11–22. https://doi.org/10.1016/j.jconhyd.2017.04.005

Mikutta, R., Kleber, M., Torn, M. S., & Jahn, R. (2006). Stabilization of soil organic matter: Association with minerals or chemical recalcitrance? *Biogeochemistry*, *77*(1), 25–56. https://doi.org/10.1007/s10533-005-0712-6

Miltner, A., Bombach, P., Schmidt-Brucken, B., & Kastner, M. (2012). SOM genesis: microbial biomass as a significant source. *Biogeochemistry*, *111*(1), 41–55.

Mohanty, S. K., Bulicek, M. C. D., Metge, D. W., Harvey, R. W., Ryan, J. N., & Boehm, A. B. (2015). Mobilization of Microspheres from a Fractured Soil during Intermittent Infiltration Events. *Vadose Zone Journal*, *14*(1), 0. https://doi.org/10.2136/vzj2014.05.0058

Ottley, C. J., Davison, W., & Edmunds, W. M. (1997). Chemical catalysis of nitrate reduction by iron(II). *Geochimica et Cosmochimica Acta*, *61*(9), 1819–1828. https://doi.org/10.1016/S0016-7037(97)00058-6

Pennino, M. J., Compton, J. E., & Leibowitz, S. G. (2017). Trends in Drinking Water Nitrate Violations Across the United States. *Environmental Science and Technology*, *51*(22), 13450–13460. https://doi.org/10.1021/acs.est.7b04269

Putz, M., Schleusner, P., Rütting, T., & Hallin, S. (2018). Relative abundance of denitrifying and DNRA bacteria and their activity determine nitrogen retention or loss in agricultural soil. *Soil Biology and Biochemistry*, *123*(February), 97–104. https://doi.org/10.1016/j.soilbio.2018.05.006

Rasmussen, C., Heckman, K., Wieder, W. R., Keiluweit, M., Lawrence, C. R., Berhe, A. A., Blankinship, J. C., Crow, S. E., Druhan, J. L., Hicks Pries, C. E., Marin-Spiotta, E., Plante, A. F., Schädel, C., Schimel, J. P., Sierra, C. A., Thompson, A., & Wagai, R. (2018). Beyond clay: towards an improved set of variables for predicting soil organic matter content. *Biogeochemistry*, *137*(3), 297–306. https://doi.org/10.1007/s10533-018-0424-3

Rees, B. T. F., Bright, D. J., Fay, R. G., Christensea, A. H., Anders, R., Baharie, B. S., Land, M. T., & Christensen, A. H. (1995). Geohydrology, water quality, and nitrogen geochemistry in the saturated and unsaturated zones beneath various land uses, Riverside and San Bernadino Counties, California, 1991-93. *US Geological Survey Water Resources Investigations Report*.

Robertson, G. Philip, Coleman, D. C., Bledsoe, C. S., & Sollins, P. (Eds.). (1999). *Standard Soil Methods for Long-Term Ecological Research* (1st ed.). Oxford University Press.

Robertson, G.P., & Groffman, P. M. (2015). Nitrogen Transformations. In E. A. Paul (Ed.), *Soil Microbiology, Ecology, and Biochemistry* (4th ed., pp. 421–446). Academic Press.

Rubol, S., Manzoni, S., Bellin, A., & Porporato, A. (2013). Modeling soil moisture and oxygen effects on soil biogeochemical cycles including dissimilatory nitrate reduction to ammonium (DNRA). *Advances in Water Resources*, *62*, 106–124. https://doi.org/10.1016/j.advwatres.2013.09.016

Schaider, L. A., Swetschinski, L., Campbell, C., & Rudel, R. A. (2019). Environmental justice and drinking water quality: Are there socioeconomic disparities in nitrate levels in U.S. drinking water? *Environmental Health: A Global Access Science Source*, *18*(1), 1–15. https://doi.org/10.1186/s12940-018-0442-6

Schmidt, M. W. I., Torn, M. S., Abiven, S., Dittmar, T., Guggenberger, G., Janssens, I. A., Kleber, M., Kögel-Knabner, I., Lehmann, J., Manning, D. A. C., Nannipieri, P., Rasse, D. P., Weiner, S., & Trumbore, S. E. (2011). Persistence of soil organic matter as an ecosystem property. *Nature*, *478*(7367), 49–56. https://doi.org/10.1038/nature10386

Seal Analytical. (2012). *Method EPA-103-A: AQ2 method Ammonia–N in Drinking and Surface Waters, Domestic and Industrial Wastes*.

Smirnoff, N., & Steward, G. R. (1985). Nitrate assimilation and translocation by higher plants: Comparative physiology and ecological consequences. *Physiologia Plantarum*, *64*(2), 133–140.

Temkin, A., Evans, S., Manidis, T., Campbell, C., & Naidenko, O. V. (2019). Exposure-based assessment and economic valuation of adverse birth outcomes and cancer risk due to nitrate in United States drinking water. *Environmental Research*, *December 2018*, 108442. https://doi.org/10.1016/j.envres.2019.04.009

Tiedje, J. M. (1988). Ecology of Denitrification and Dissimilatory Nitrate Reduction to Ammonium. In *Environmental Microbiology of Anaerobes* (pp. 179–244). https://doi.org/10.1038/ismej.2007.109

Totsche, K. U., Amelung, W., Gerzabek, M. H., Guggenberger, G., Klumpp, E., Knief, C., Lehndorff, E., Mikutta, R., Peth, S., Prechtel, A., Ray, N., & Kögel-Knabner, I. (2018). Microaggregates in soils. *Journal of Plant Nutrition and Soil Science*, *181*(1), 104–136. https://doi.org/10.1002/jpln.201600451

Wang, S., Radny, D., Huang, S., Zhuang, L., Zhao, S., Berg, M., Jetten, M. S. M., & Zhu, G. (2017). Nitrogen loss by anaerobic ammonium oxidation in unconfined aquifer soils. *Scientific Reports*, *7*(December 2016), 1–10. https://doi.org/10.1038/srep40173

Wiesmeier, M., Urbanski, L., Hobley, E., Lang, B., von Lützow, M., Marin-Spiotta, E., van Wesemael, B., Rabot, E., Ließ, M., Garcia-Franco, N., Wollschläger, U., Vogel, H. J., & Kögel-Knabner, I. (2019). Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales. *Geoderma*, *333*(July 2018), 149–162. https://doi.org/10.1016/j.geoderma.2018.07.026

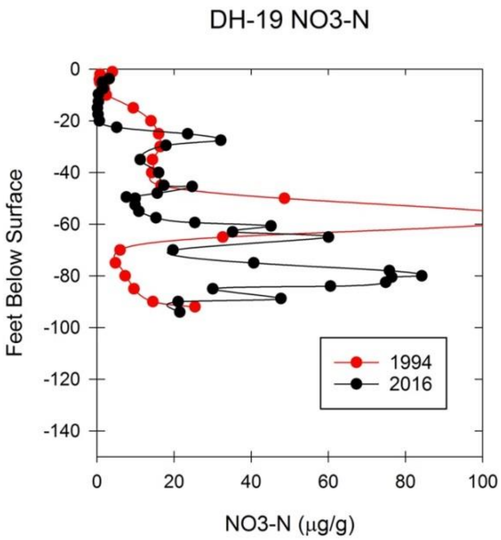
Xin, J., Liu, Y., Chen, F., Duan, Y., Wei, G., Zheng, X., & Li, M. (2019). The missing nitrogen pieces: A critical review on the distribution, transformation, and budget of nitrogen in the vadose zone-groundwater system. *Water Research*, *165*, 114977. https://doi.org/10.1016/j.watres.2019.114977

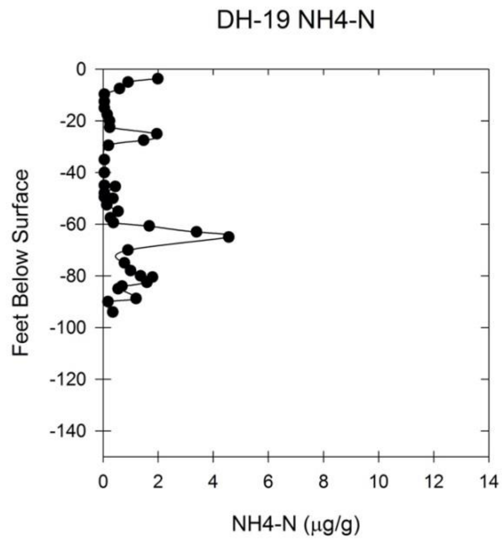
Zhang, J., Lan, T., Muller, C., & Cai, Z. (2015). Dissimilatory nitrate reduction to ammonium (DNRA) plays an important role in soil nitrogen conservation in neutral and alkaline but not acidic rice soil. *Journal of Soil Sediments*, *15*(3), 523–531.

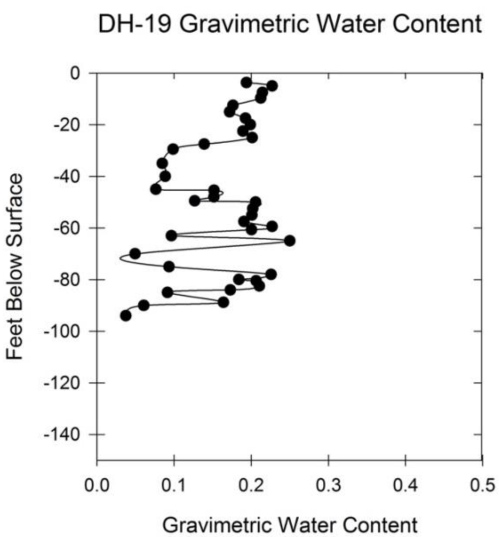
Zheng, C., Lu, Y., Liu, X., Šimůnek, J., Zeng, Y., Shi, C., & Li, H. (2020). In-situ monitoring and characteristic analysis of freezing-thawing cycles in a deep vadose zone. *Water (Switzerland)*, *12*(5). https://doi.org/10.3390/W12051261

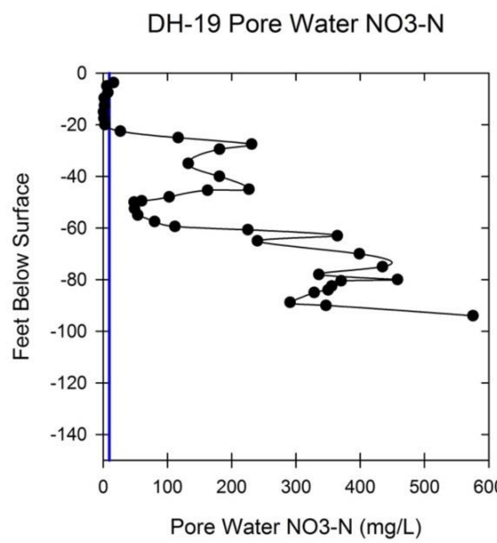
Appendix 1: Graphical Results from the 2016 CPNRD Vadose Study

DH-19-16









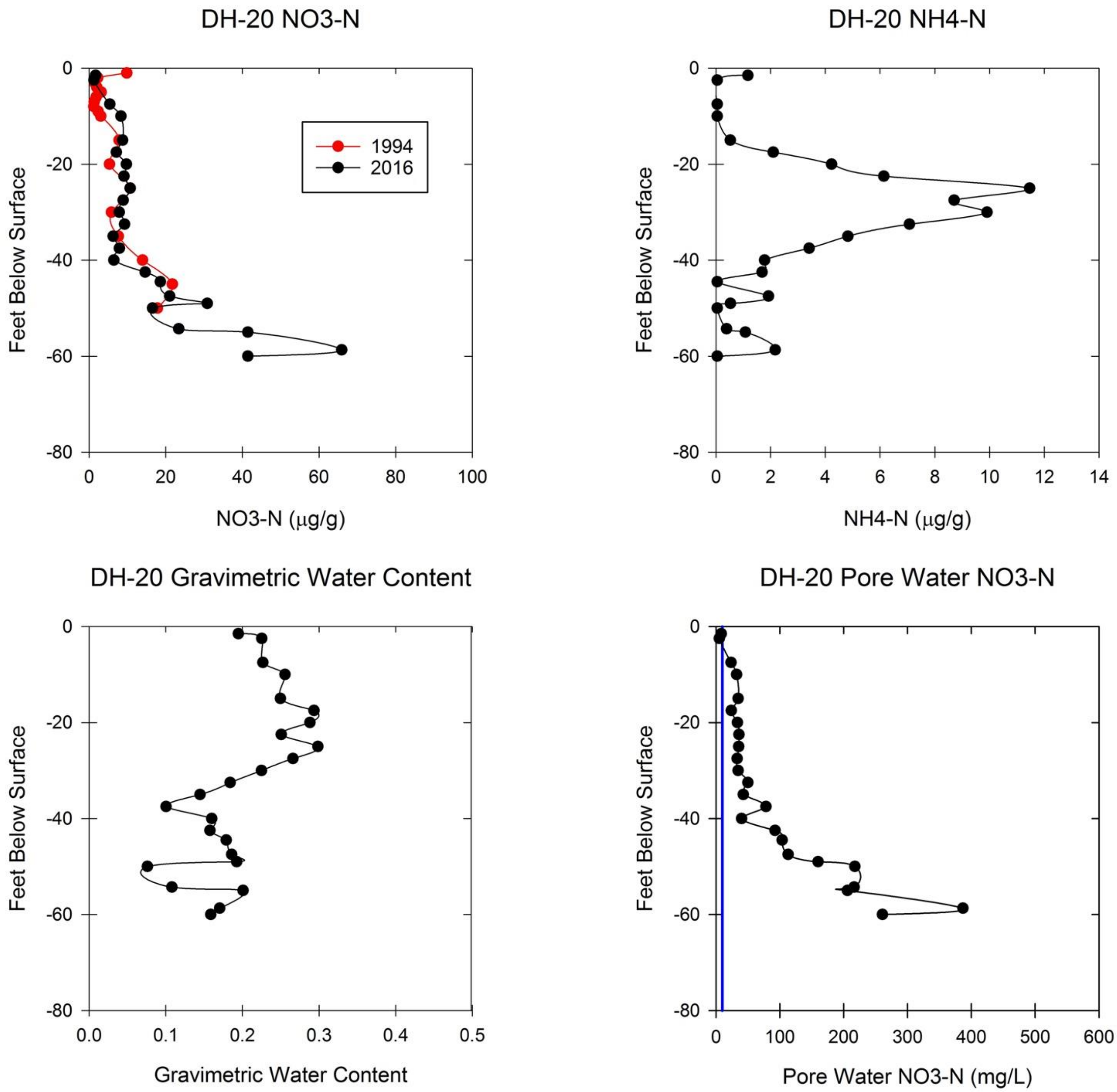
Depth to Water = 93.4'

Total NO_3-N Storage = 8,863 lbs-N/acre

Average Soil NO_3-N = 25.48 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-20-16



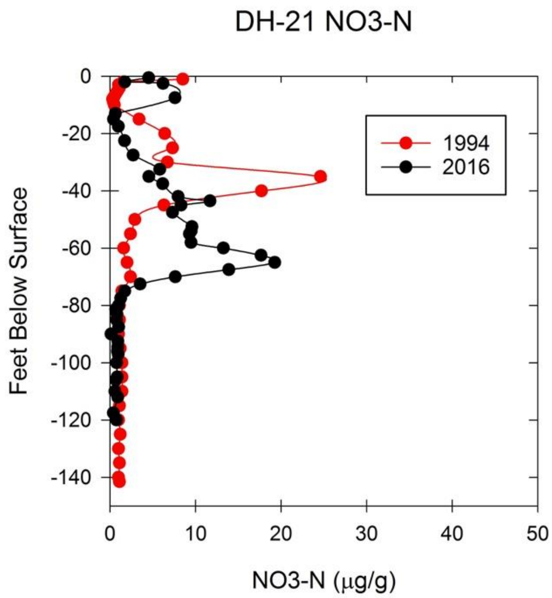
Depth to Water = 59.8’

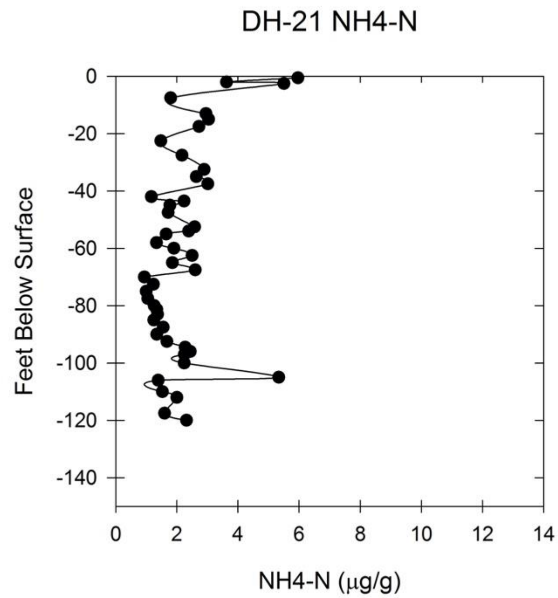
Total NO_3-N Storage = 3,318 lbs-N/acre

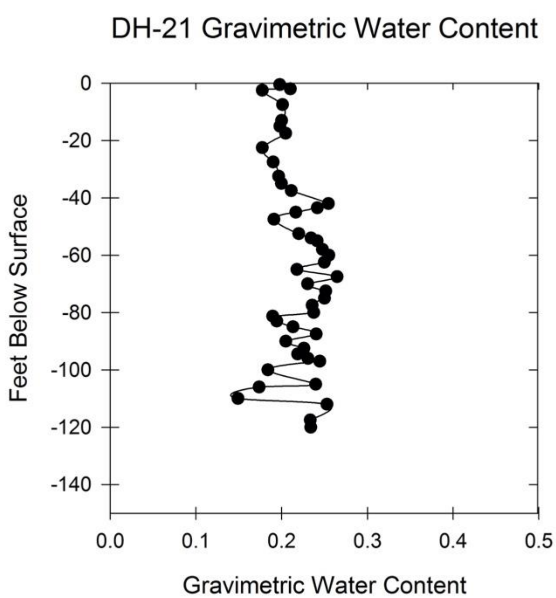
Average Soil NO_3-N = 15.90 µg/g

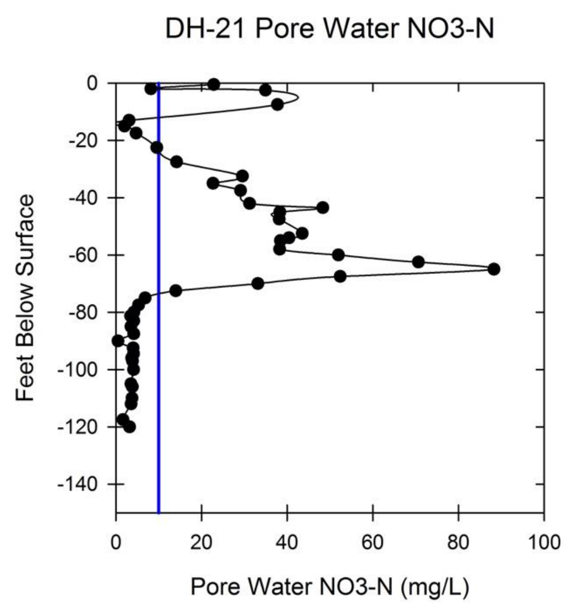
Vertical Blue Line = 10 mg/L MCL

DH-21-16









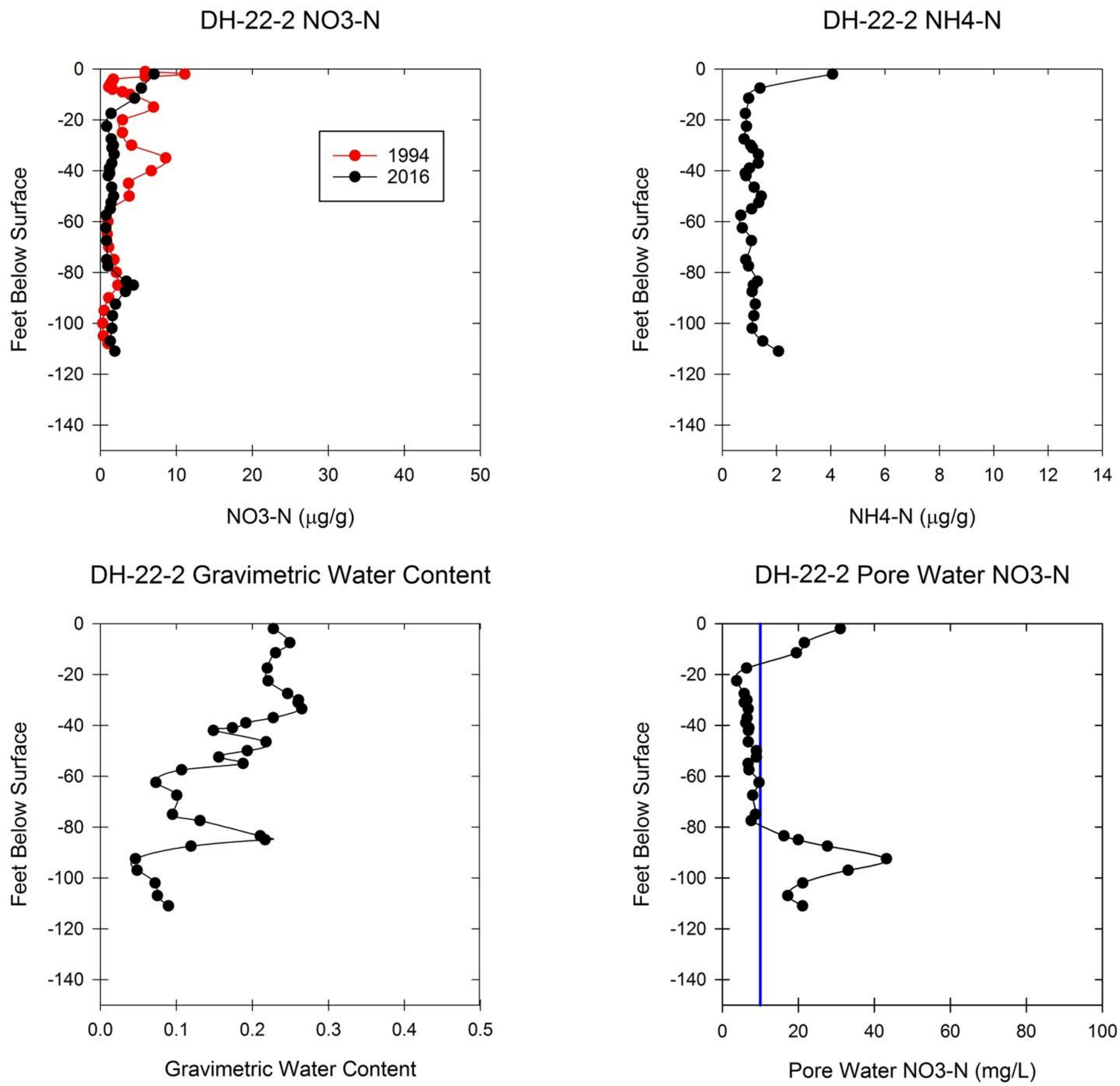
Depth to Water = 119.75’

Total NO_3-N Storage = 2,175 lbs-N/acre

Average Soil NO_3-N = 4.60 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-22-2-16



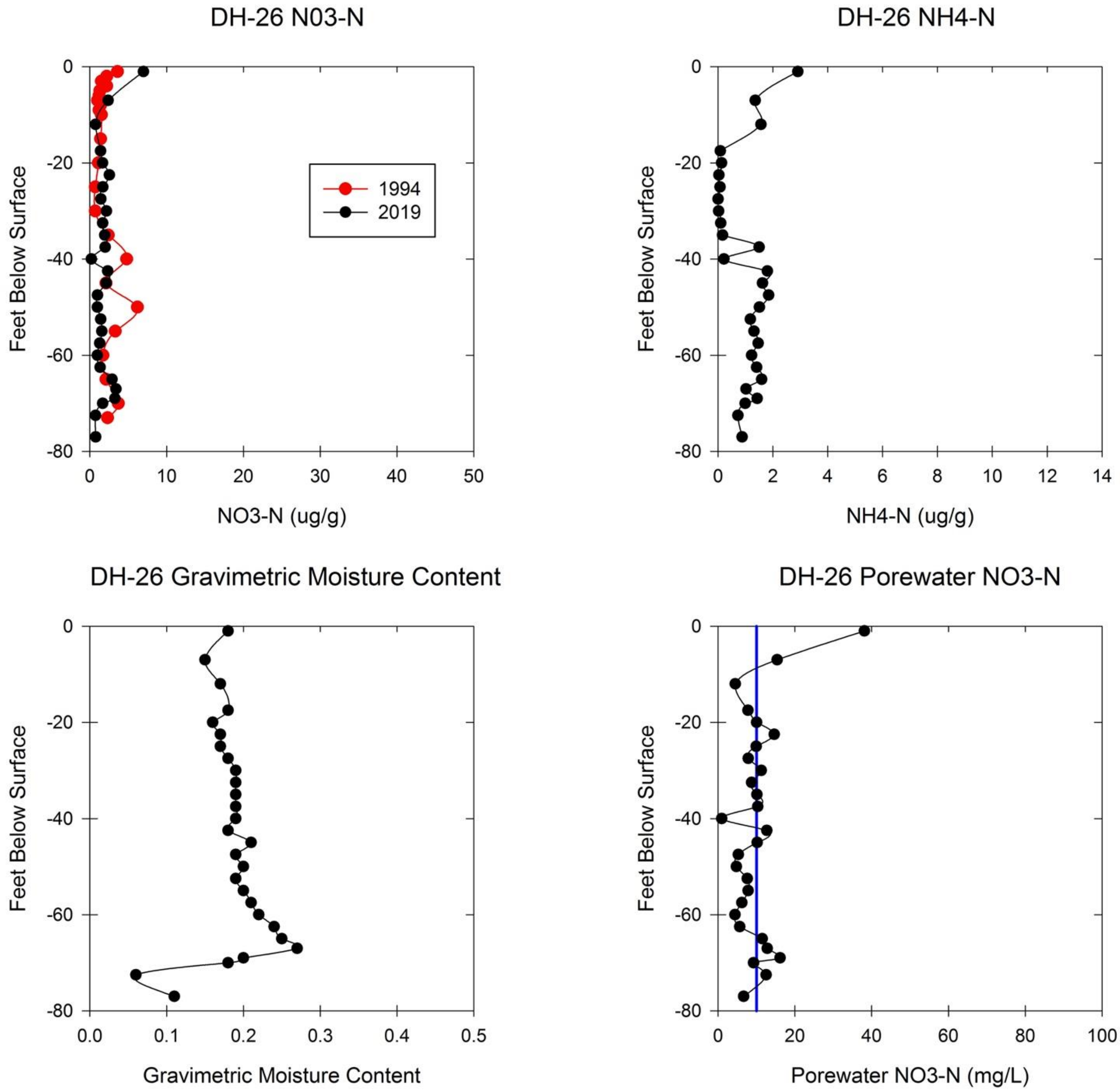
Depth to Water = 113.5’

Total NO_3-N Storage = 923 lbs-N/acre

Average Soil NO_3-N = 2.00 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-26-19



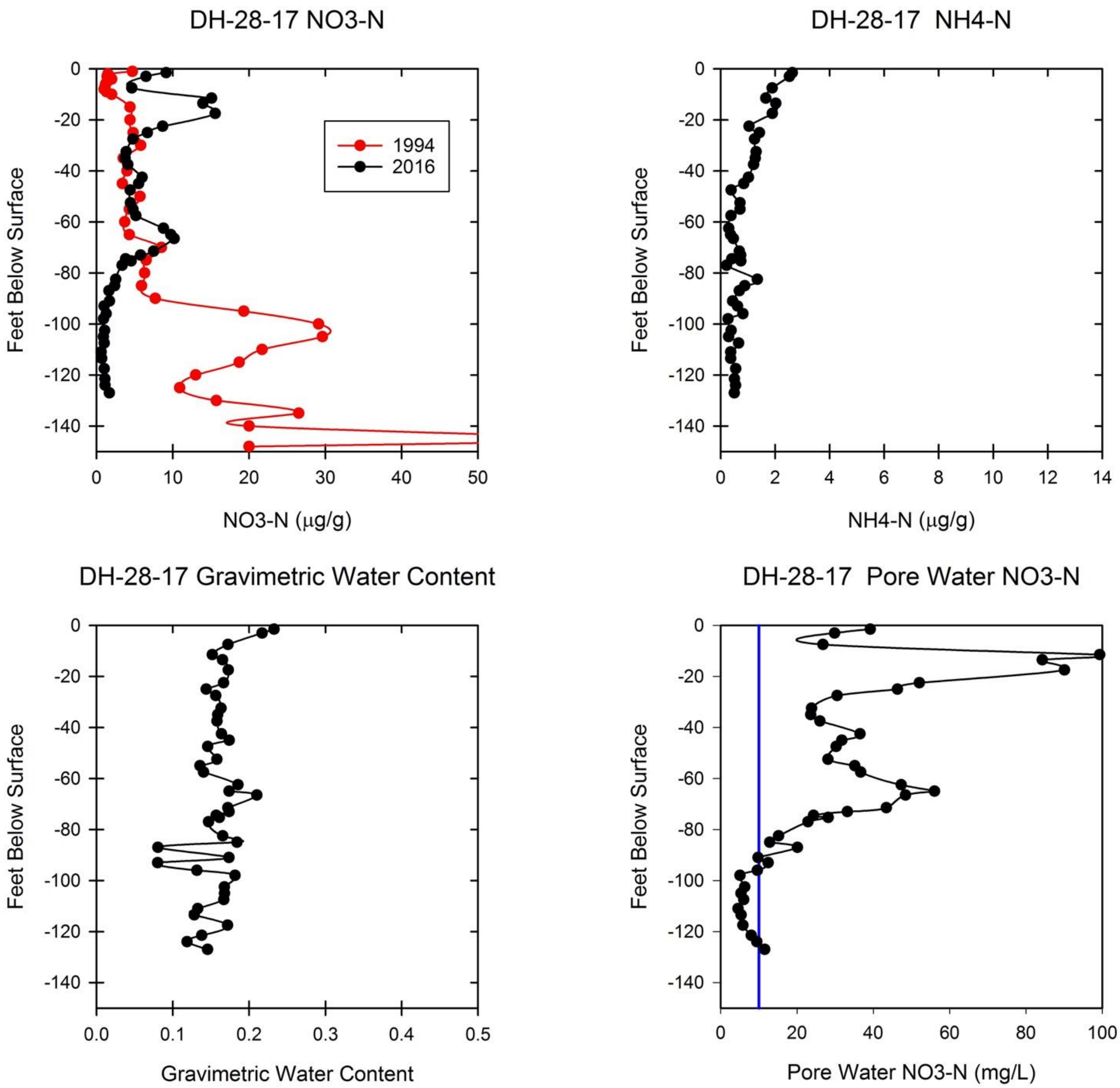
Depth to Water = 79.5’

Total NO_3-N Storage = 503 lbs-N/acre

Average Soil NO_3-N = 1.87 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-28-17



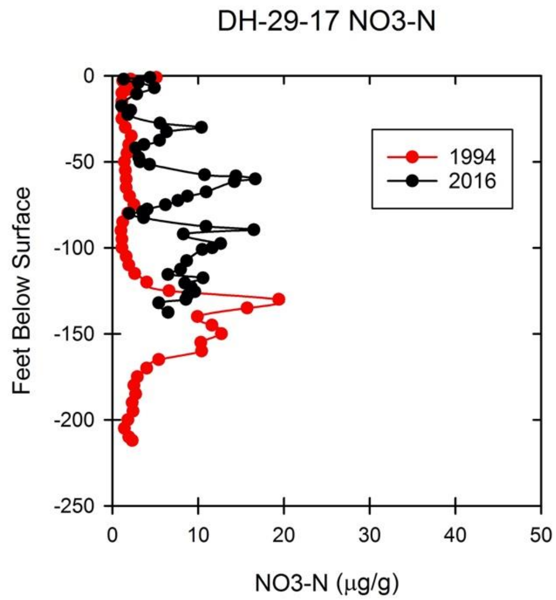
Depth to Water = Refusal at 130’

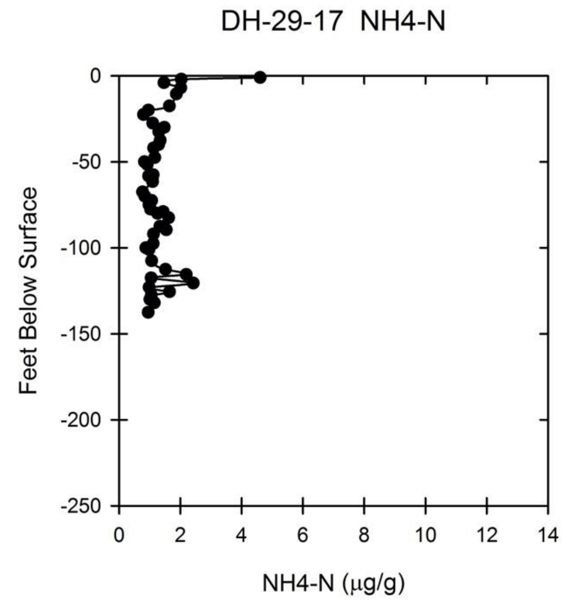
Total NO_3-N Storage = 2,357 lbs-N/acre

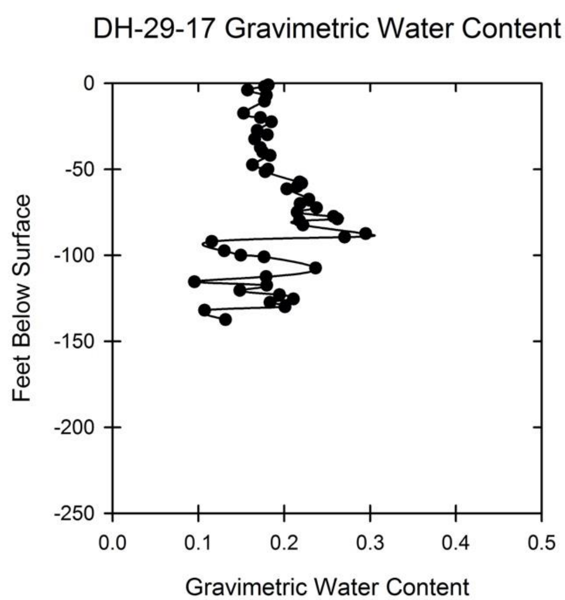
Average Soil NO_3-N = 4.79 µg/g

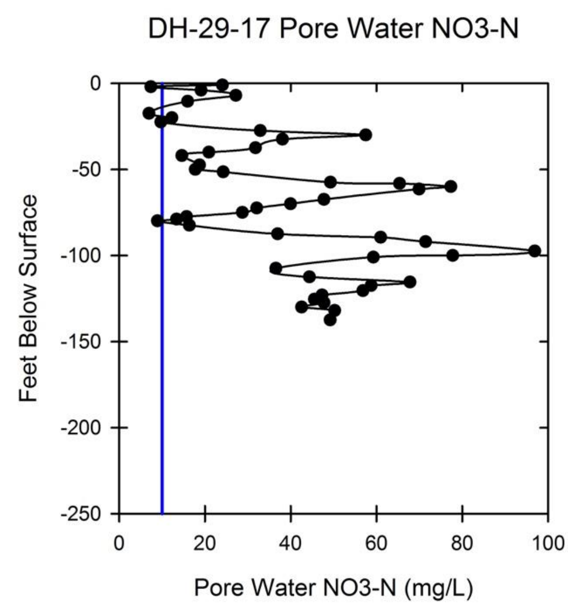
Vertical Blue Line = 10 mg/L MCL

DH-29-17









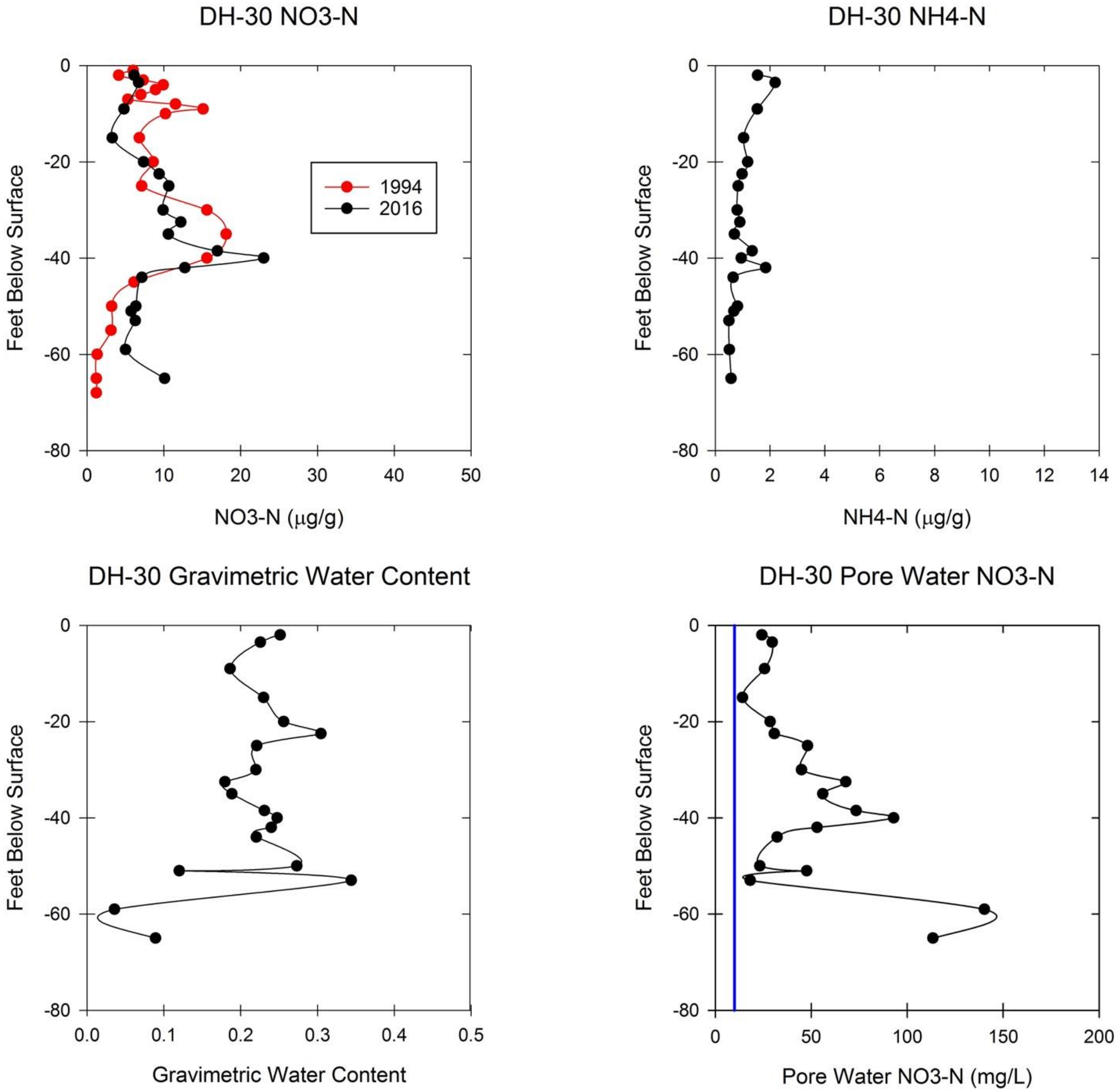
Depth to Water = Refusal at 140’

Total NO_3-N Storage = 3,938 lbs-N/acre

Average Soil NO_3-N = 7.15 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-30-17



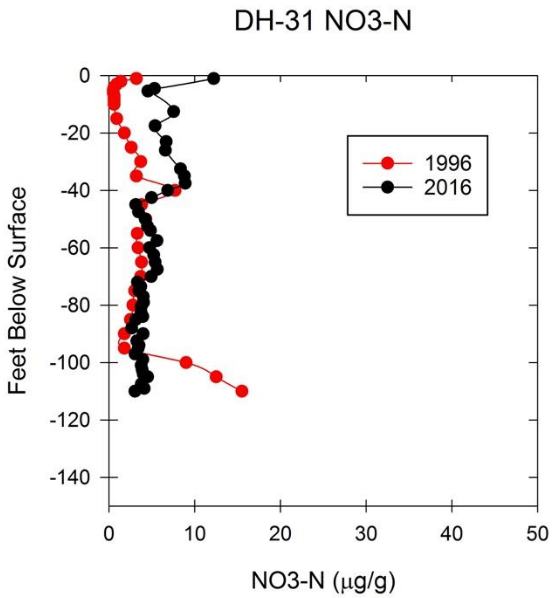
Depth to Water = 71’

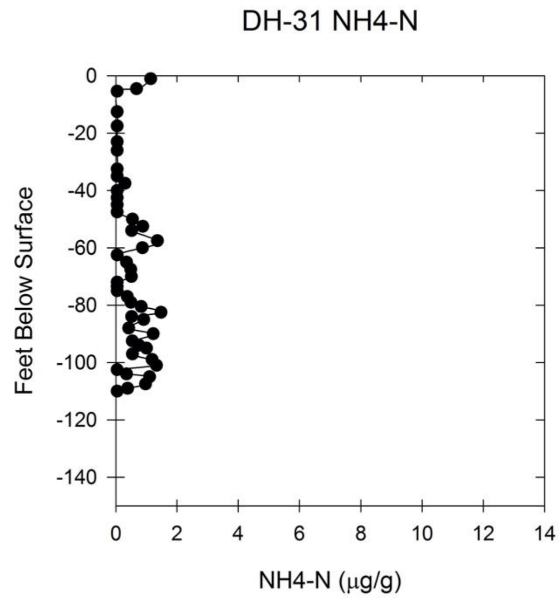
Total NO_3-N Storage = 2,195 lbs-N/acre

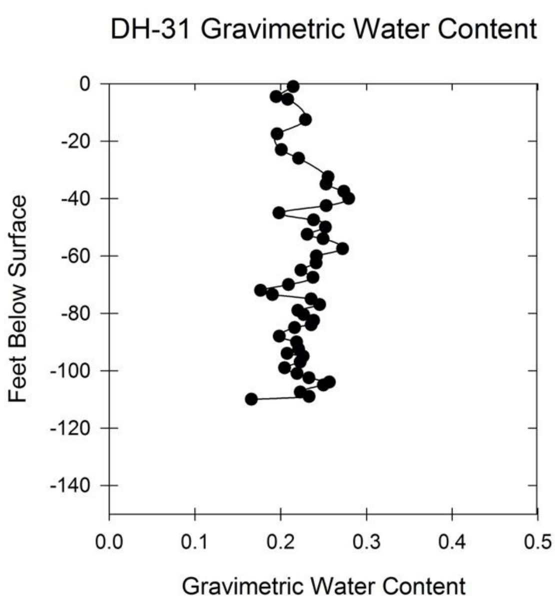
Average Soil NO_3-N = 9.16 µg/g

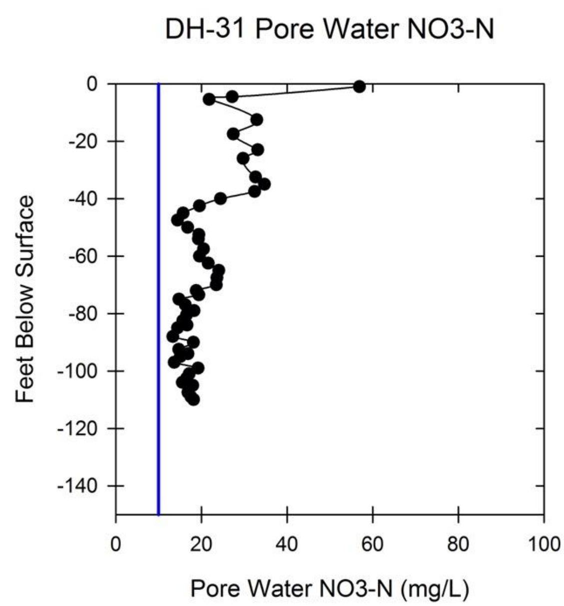
Vertical Blue Line = 10 mg/L MCL

DH-31-16









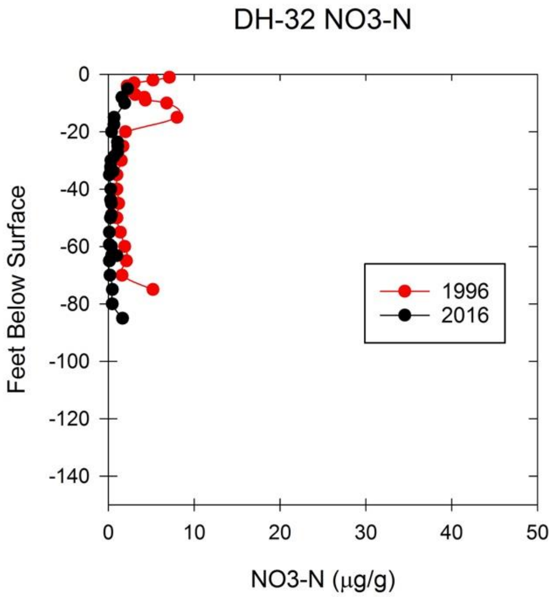
Depth to Water = 109’

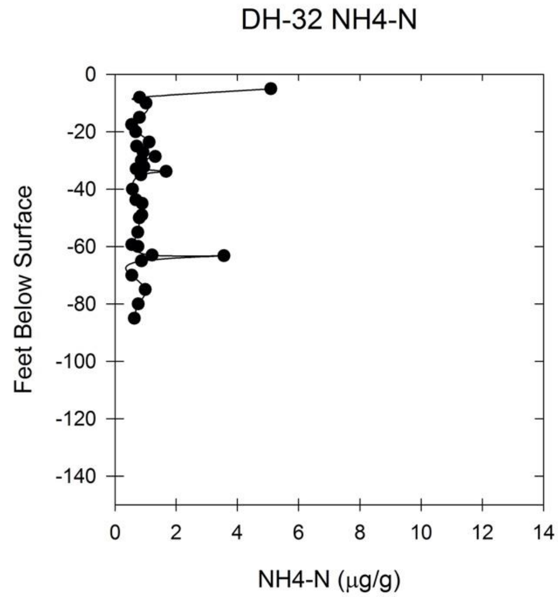
Total NO_3-N Storage = 2,293 lbs-N/acre

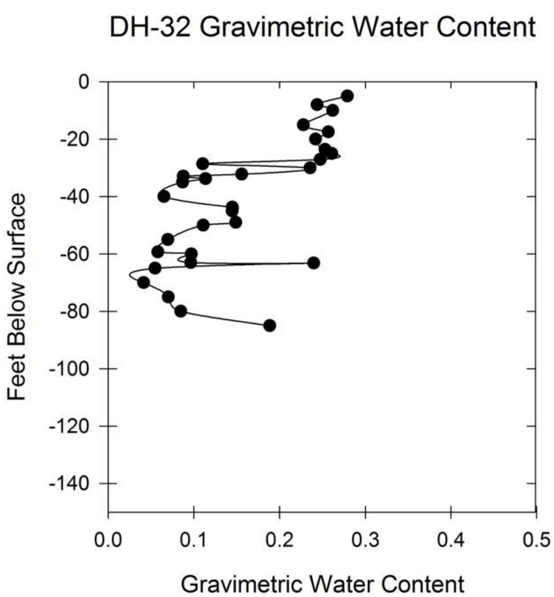
Average Soil NO_3-N = 4.81 µg/g

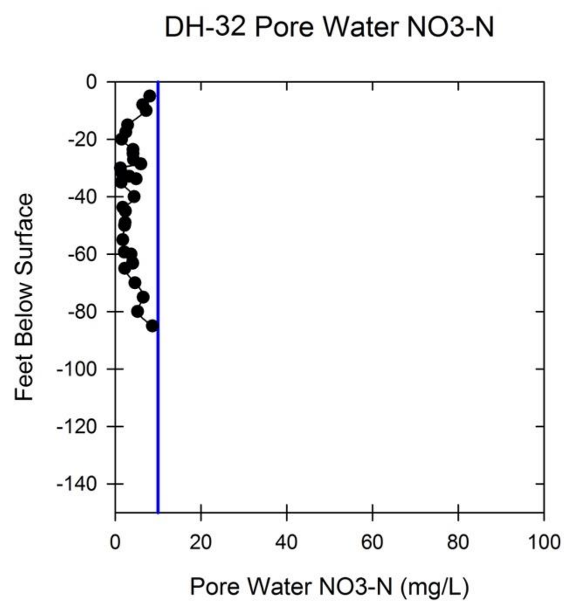
Vertical Blue Line = 10 mg/L MCL

DH-32-16









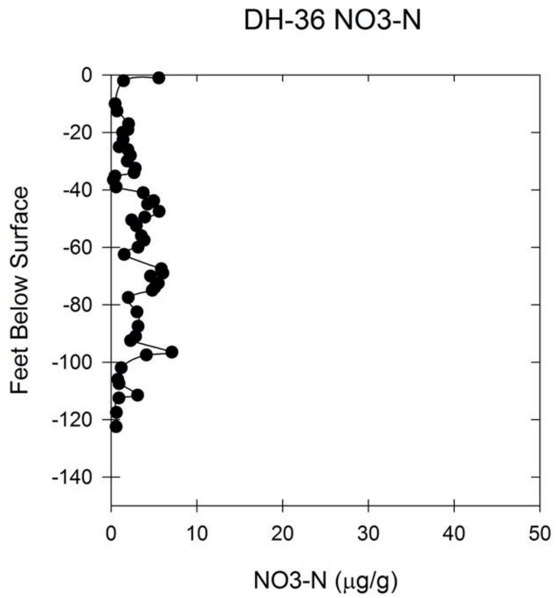
Depth to Water = 83’

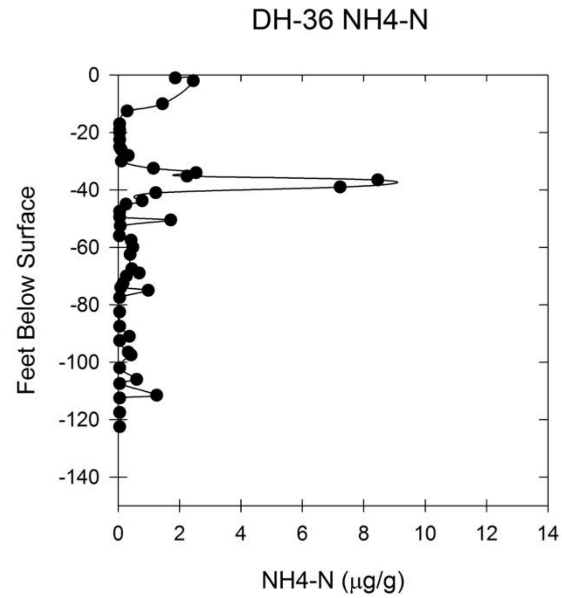
Total NO_3-N Storage = 196 lbs-N/acre

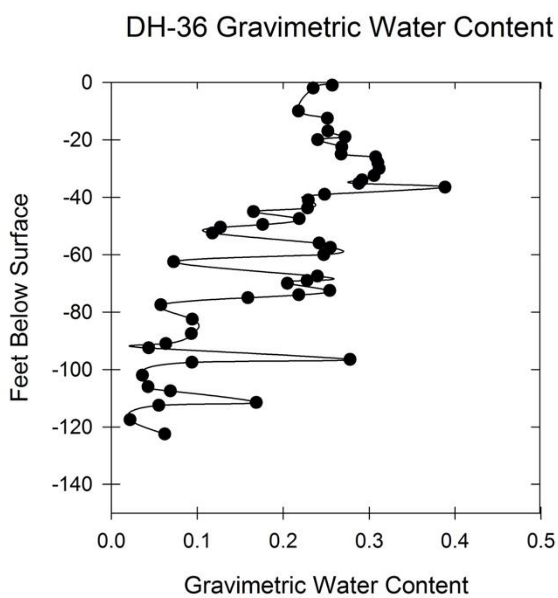
Average Soil NO_3-N = 0.64 µg/g

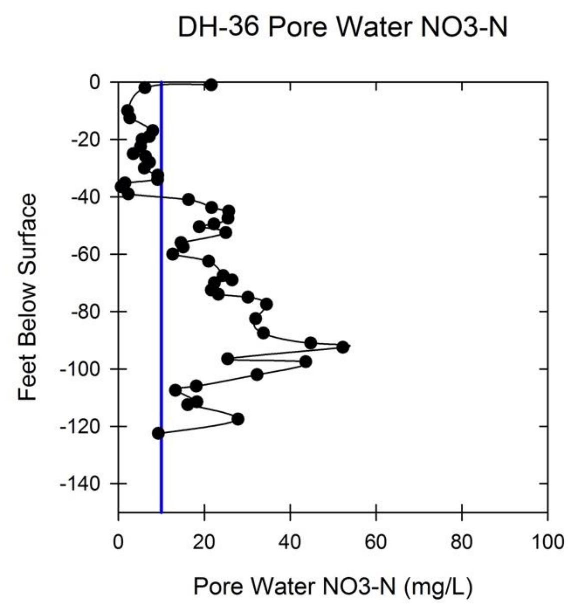
Vertical Blue Line = 10 mg/L MCL

DH-36-16









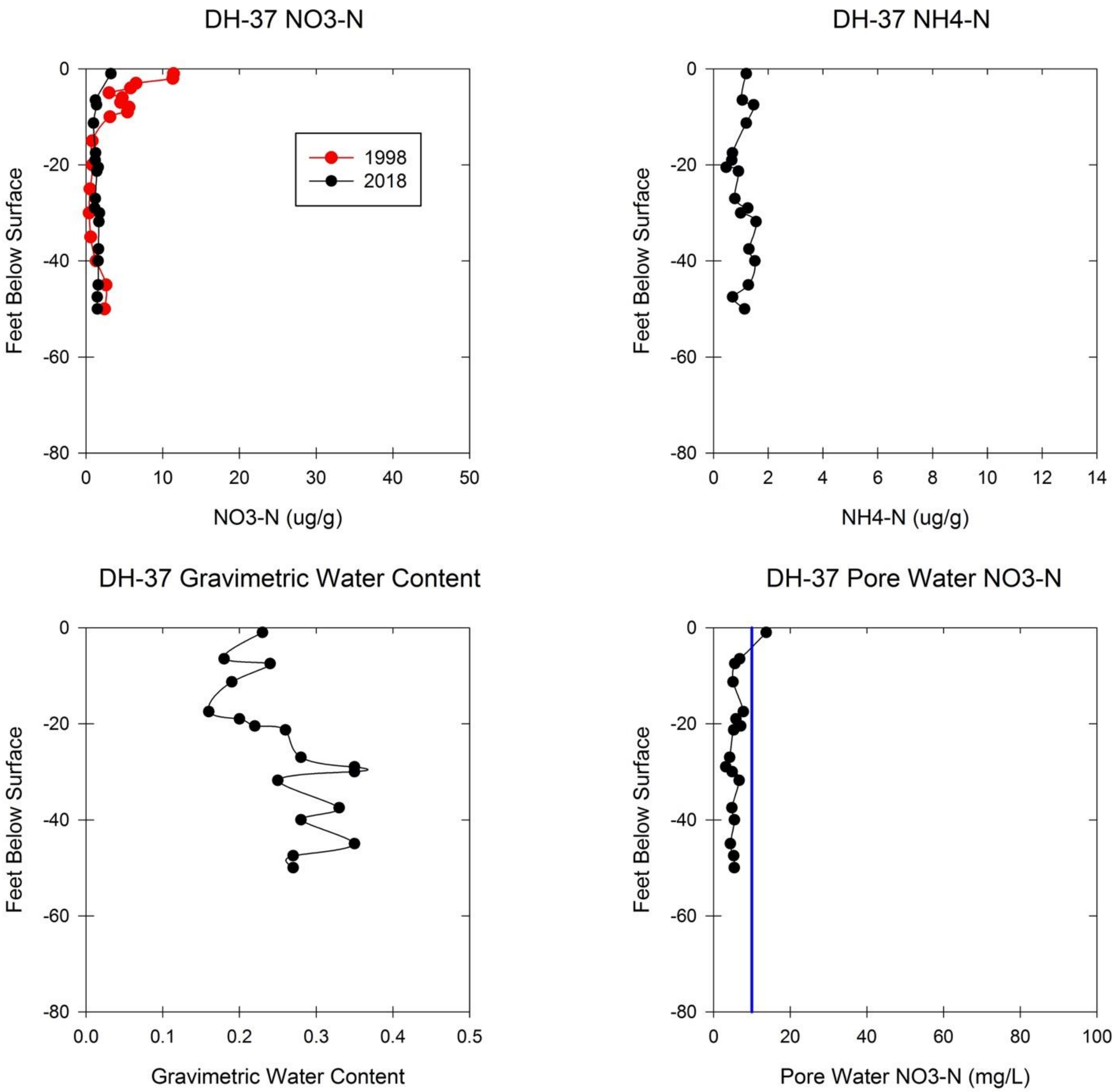
Depth to Water = 124.5'

Total NO_3-N Storage = 1,255 lbs-N/acre

Average Soil NO_3-N = 2.77 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-37-18



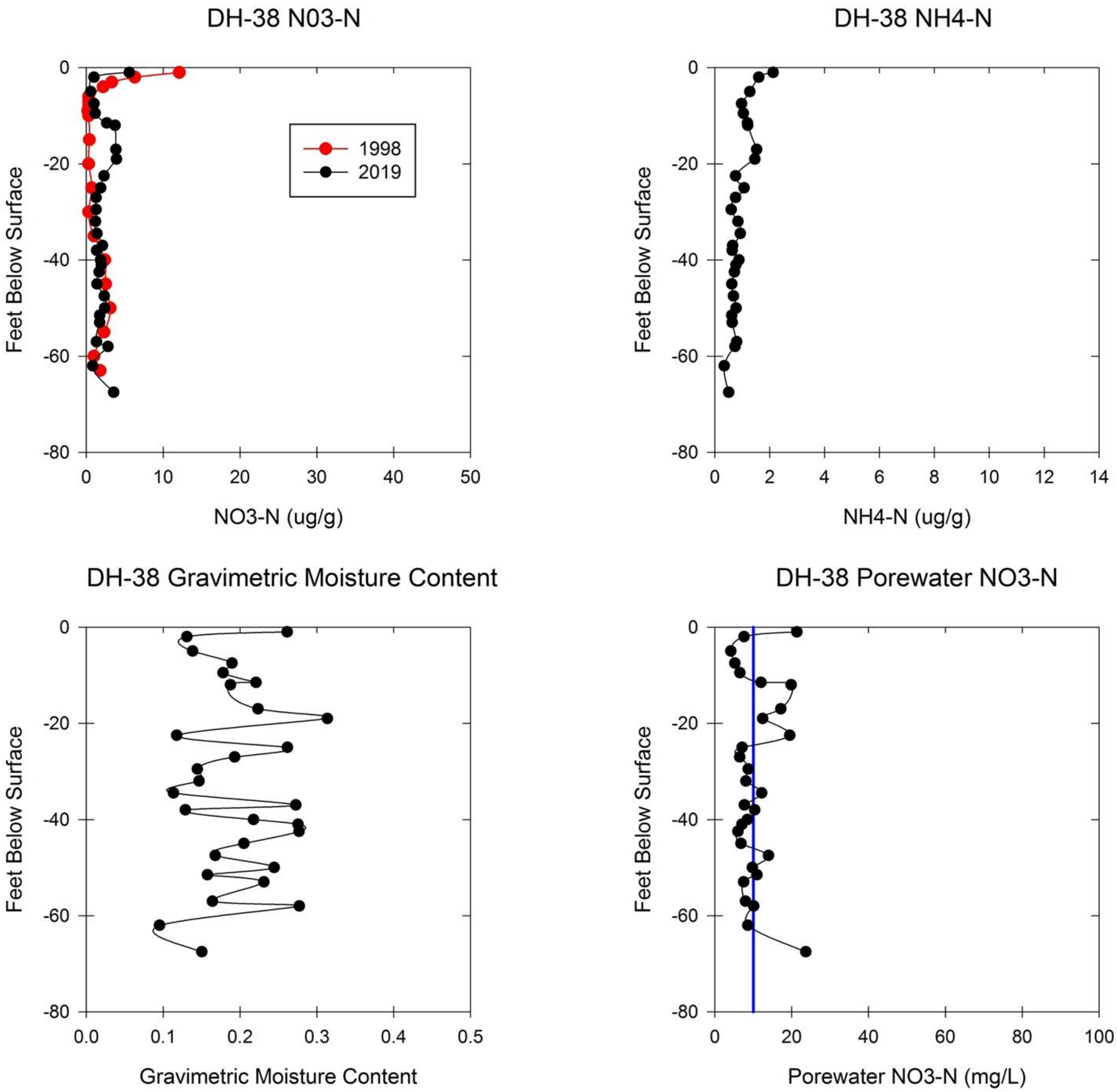
Depth to Water = 47.9’

Total NO_3-N Storage = 268 lbs-N/acre

Average Soil NO_3-N = 1.50 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-38-19



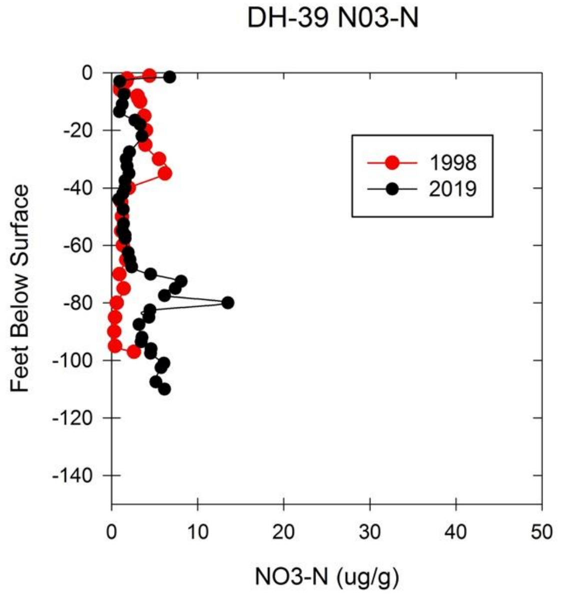
Depth to Water = 70’

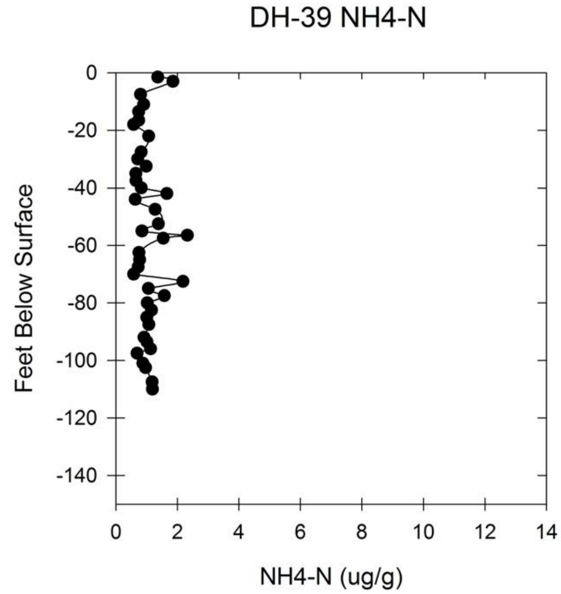
Total NO_3-N Storage = 462 lbs-N/acre

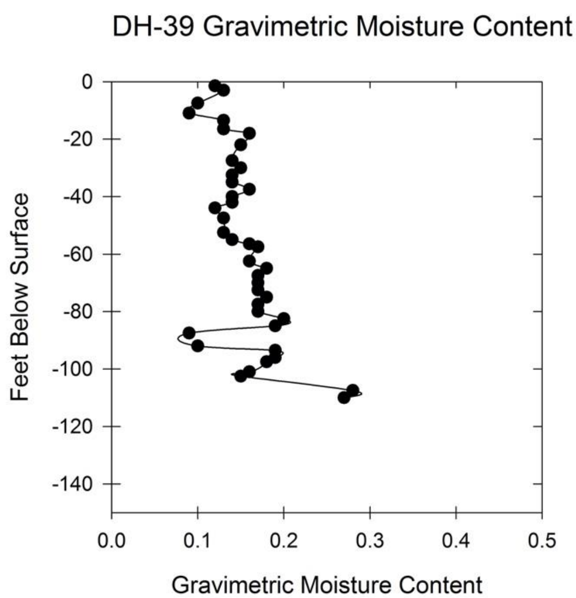
Average Soil NO_3-N = 2.06 µg/g

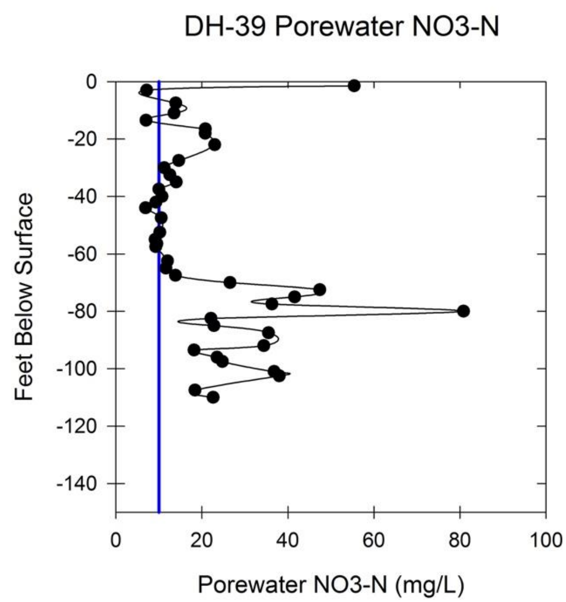
Vertical Blue Line = 10 mg/L MCL

DH-39-19









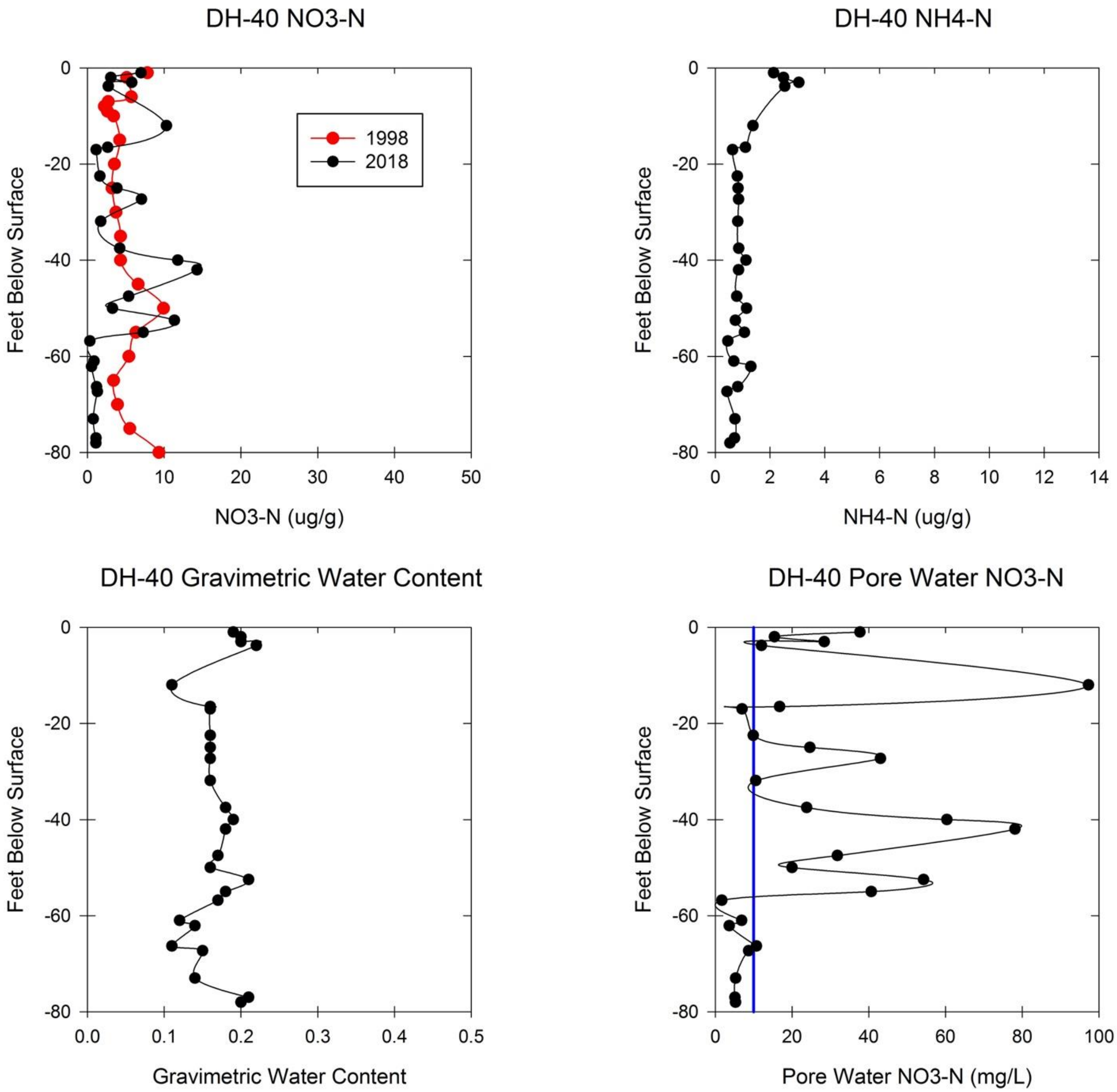
Depth to Water = 108’

Total NO_3-N Storage = 1,282 lbs-N/acre

Average Soil NO_3-N = 3.44 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-40-16



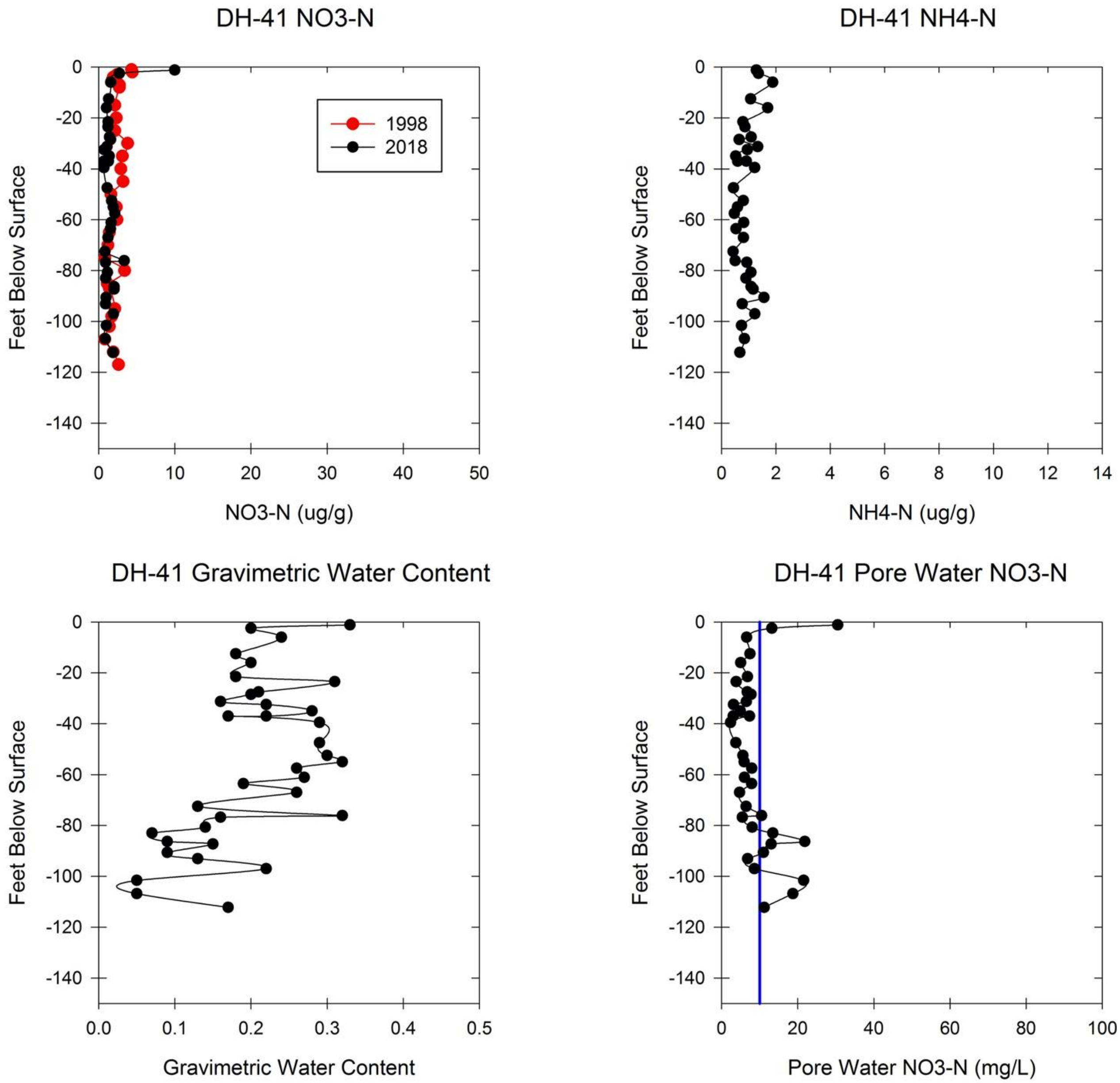
Depth to Water = Refusal at 80'

Total NO_3-N Storage = 1,289 lbs-N/acre

Average Soil NO_3-N = 4.27 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-41-18



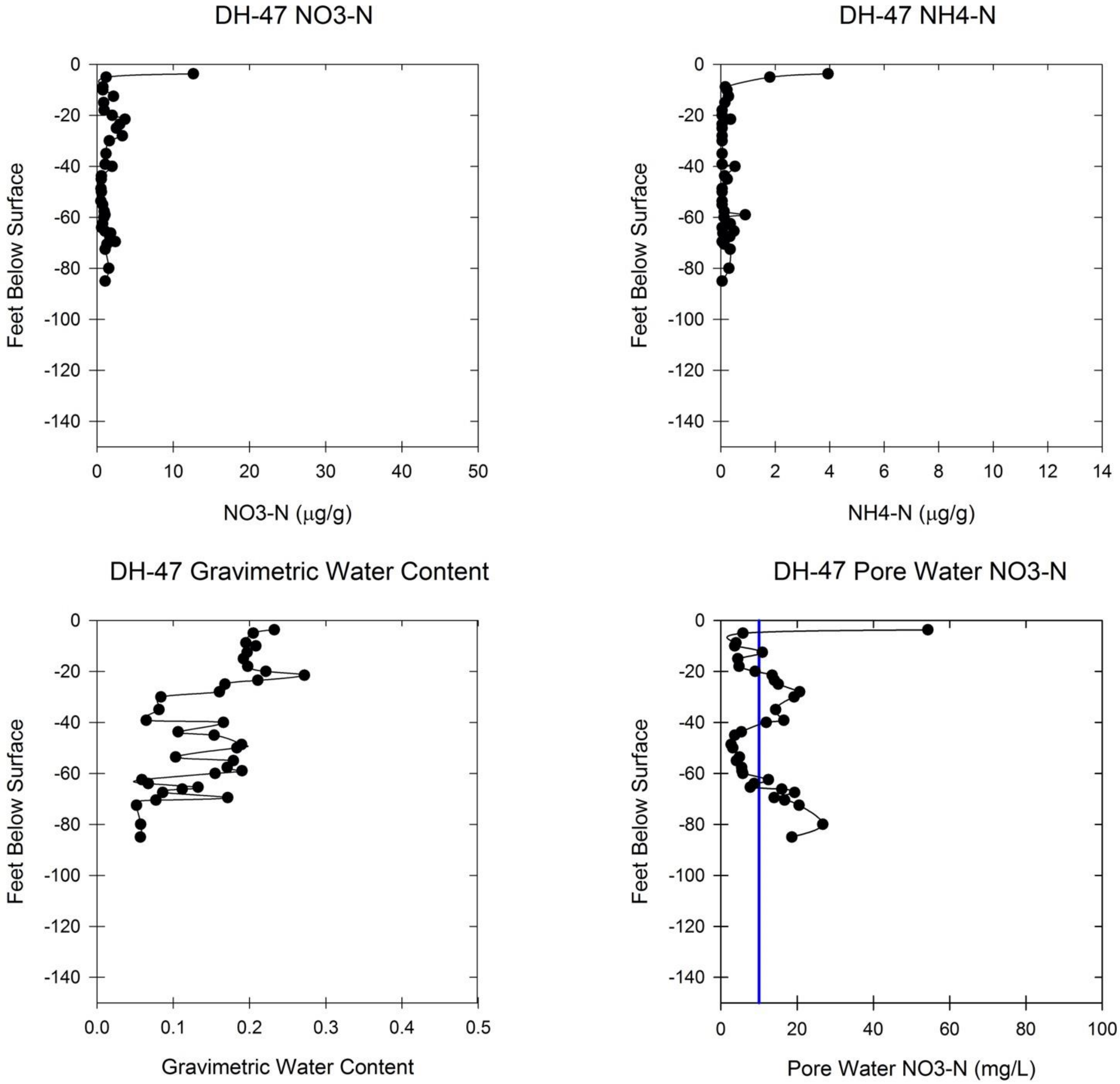
Depth to Water = 110.5’

Total NO_3-N Storage = 620 lbs-N/acre

Average Soil NO_3-N = 1.64 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-47-16



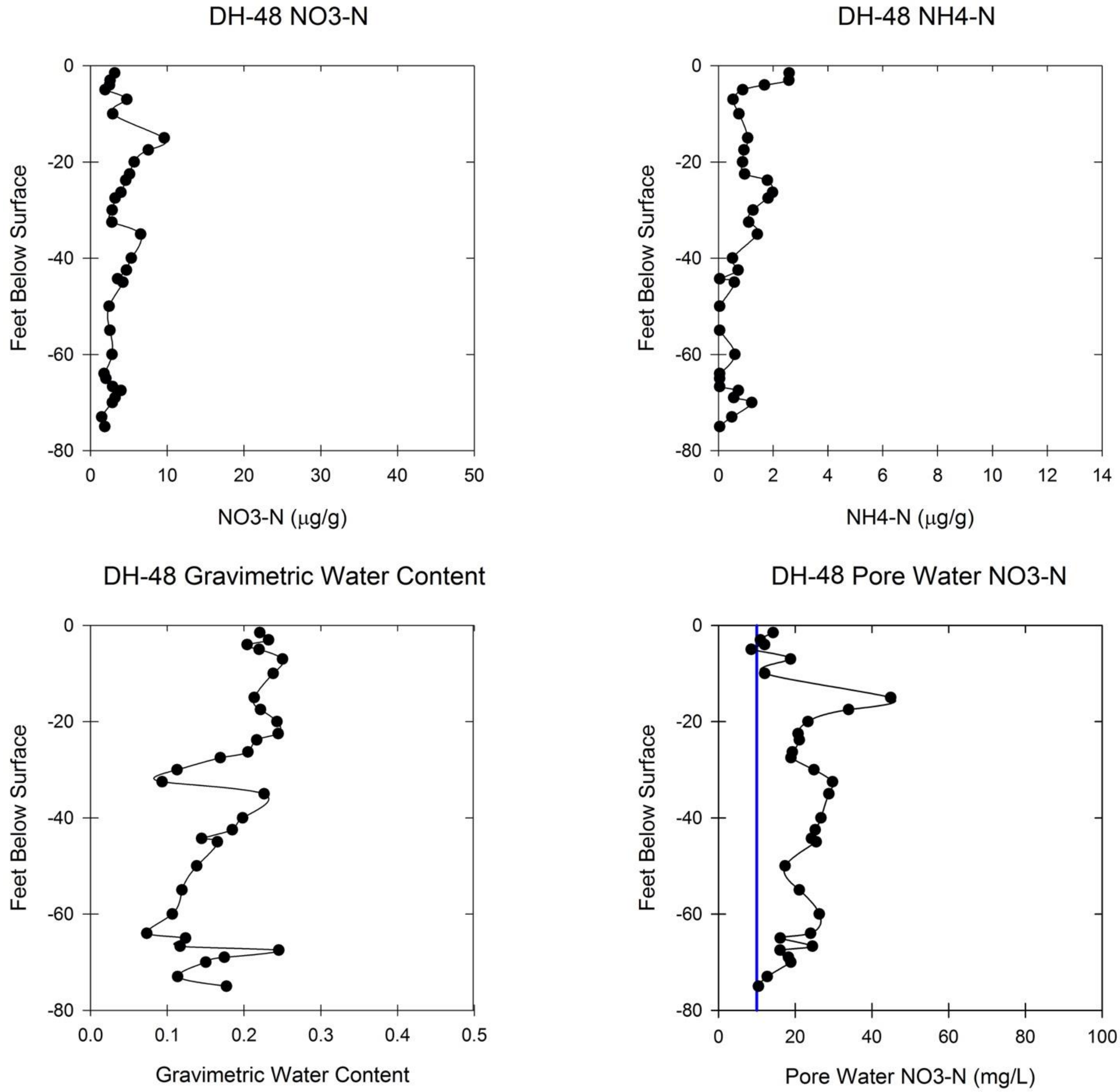
Depth to Water = 85'

Total NO_3-N Storage = 445 lbs-N/acre

Average Soil NO_3-N = 1.69 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-48-16



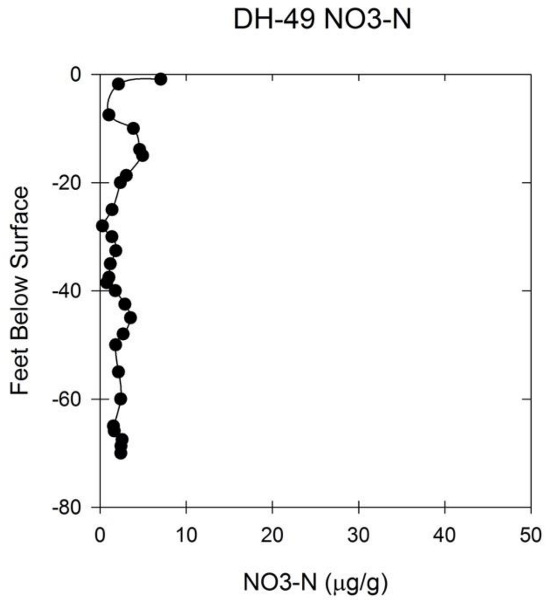
Depth to Water = 75’

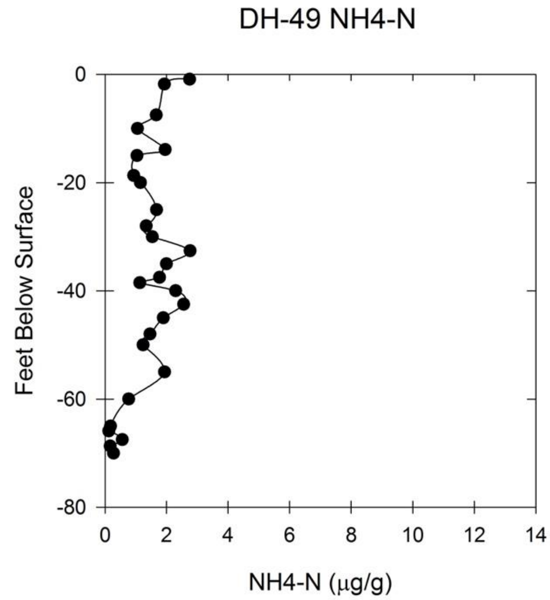
Total NO_3-N Storage = 1,070 lbs-N/acre

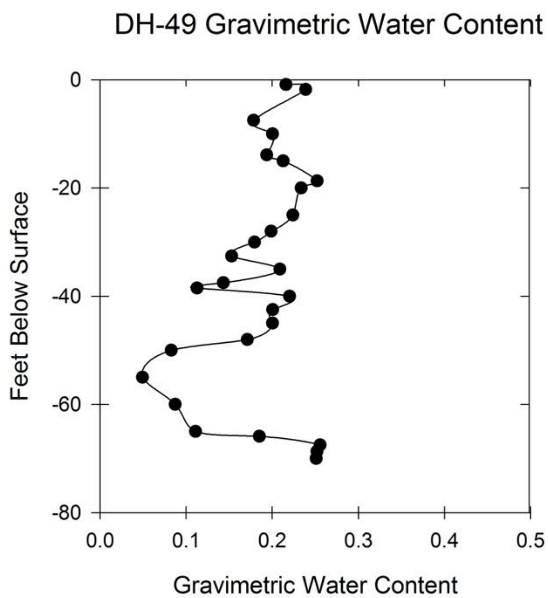
Average Soil NO_3-N = 3.65 µg/g

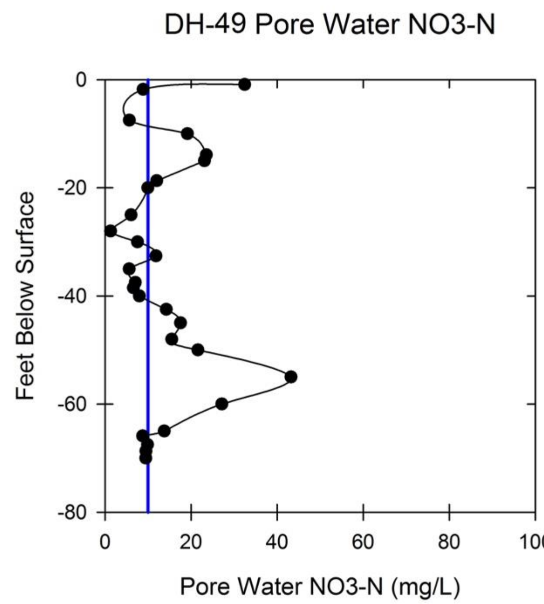
Vertical Blue Line = 10 mg/L MCL

DH-49-16









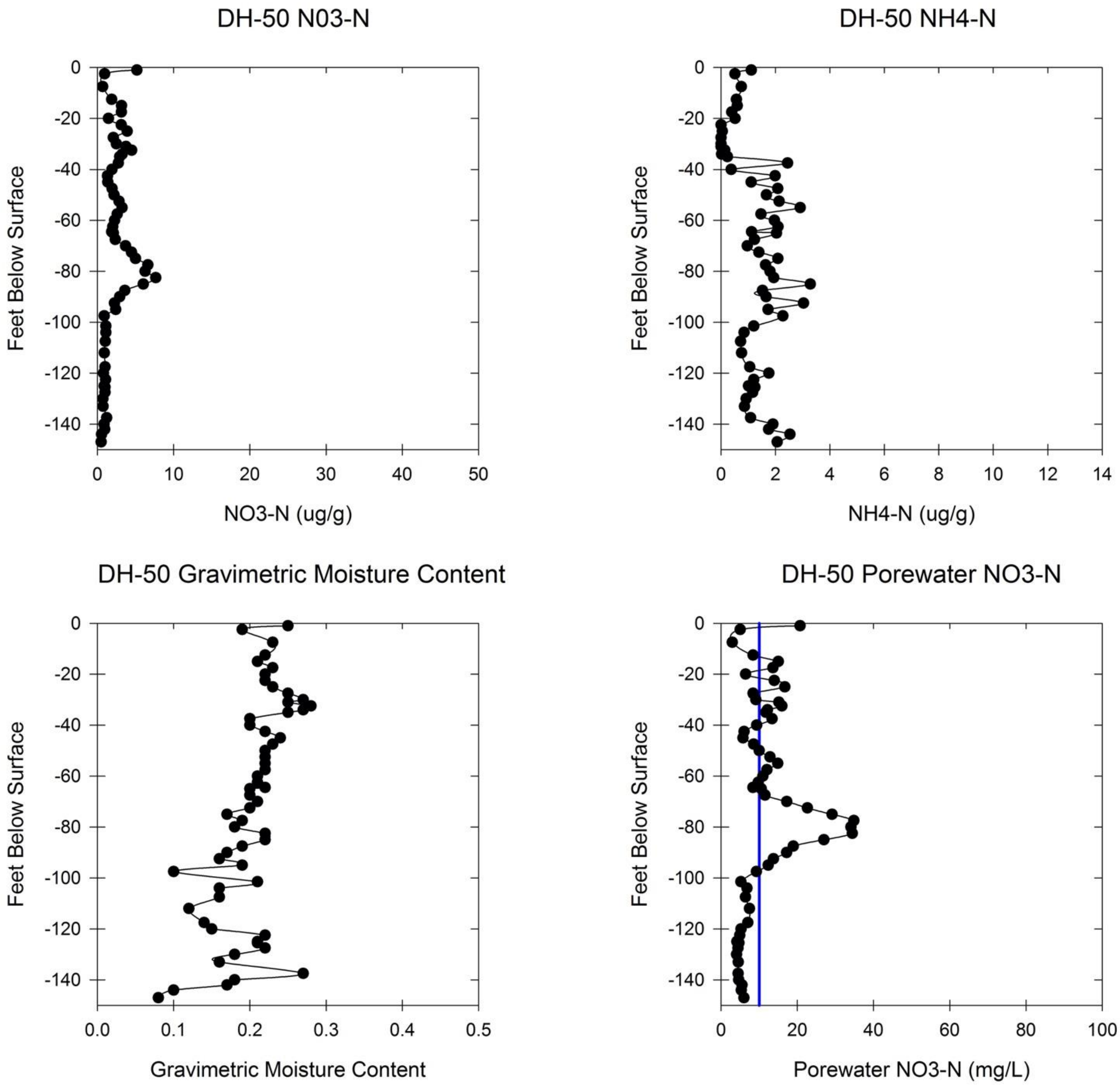
Depth to Water = 69.9’

Total NO_3-N Storage = 621 lbs-N/acre

Average Soil NO_3-N = 2.38 µg/g

Vertical Blue Line = 10 mg/L MCL

DH-50-20



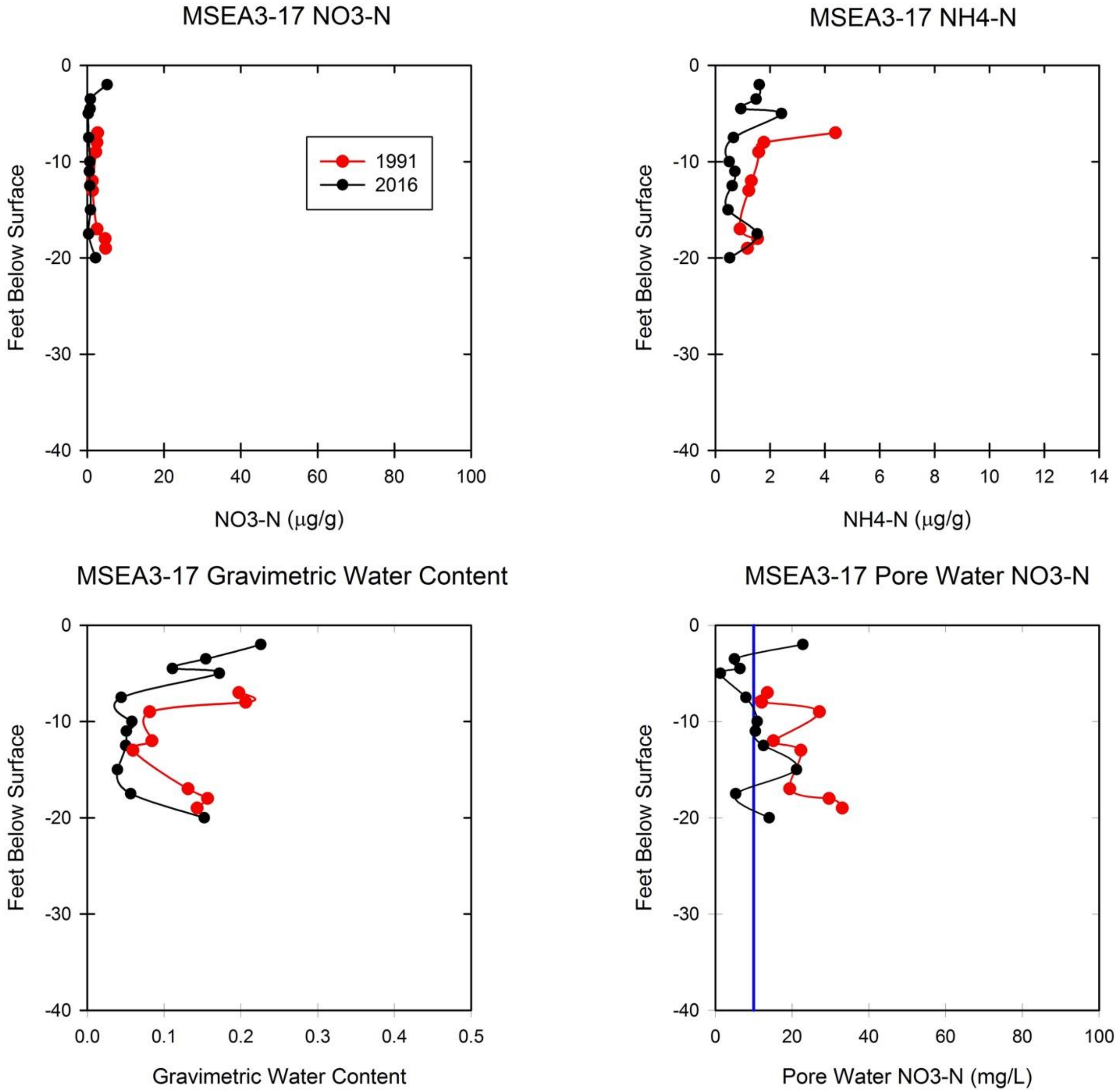
Depth to Water = Refusal 149’

Total NO_3-N Storage = 1,222 lbs-N/acre

Average Soil NO_3-N = 2.41 µg/g

Vertical Blue Line = 10 mg/L MCL

MSEA-3-17



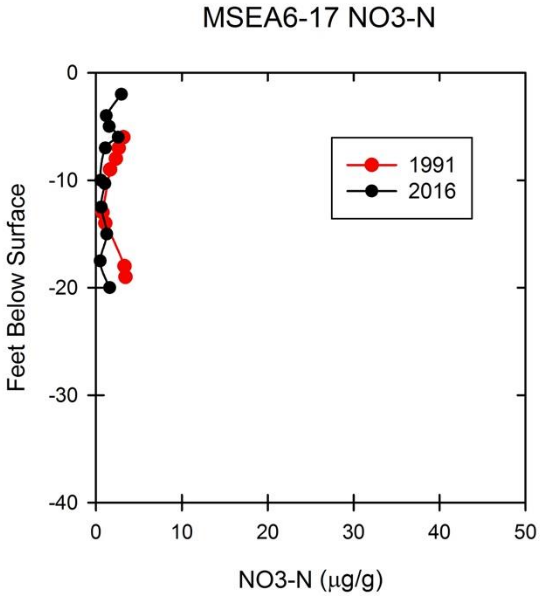
Depth to Water = 20’

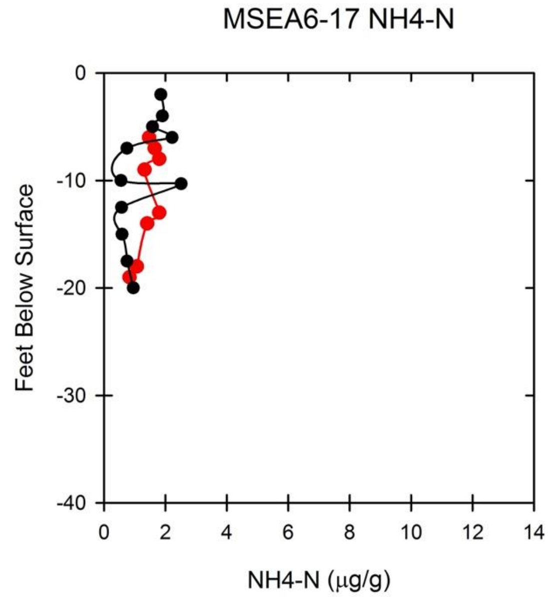
Total NO_3-N Storage = 71 lbs-N/acre

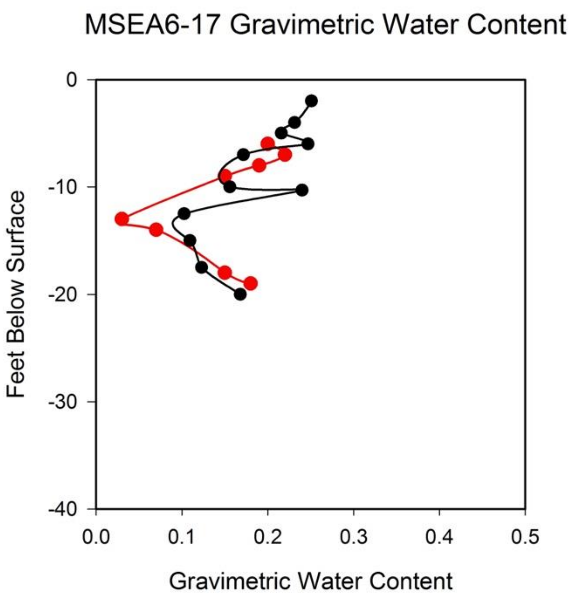
Average Soil NO_3-N = 1.11 µg/g

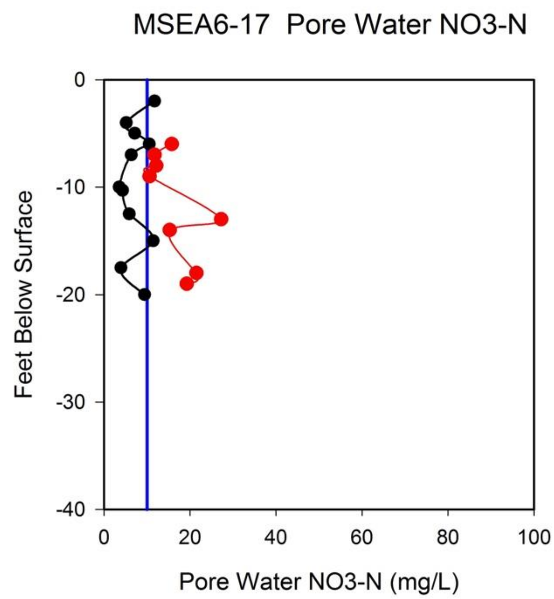
Vertical Blue Line = 10 mg/L MCL

MSEA-6-17









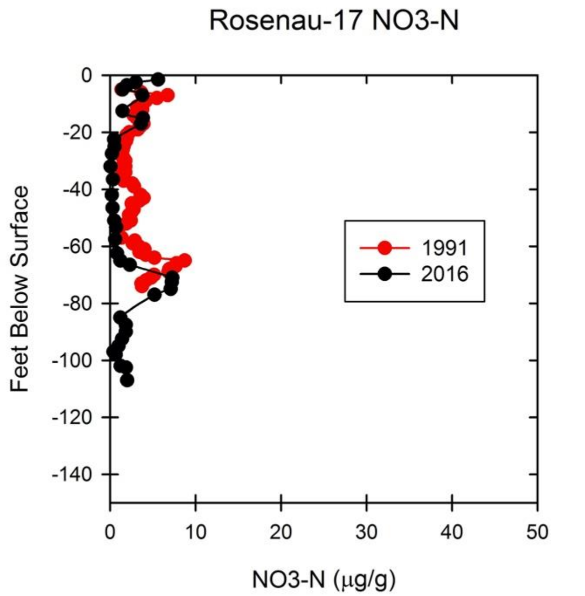
Depth to Water = 20’

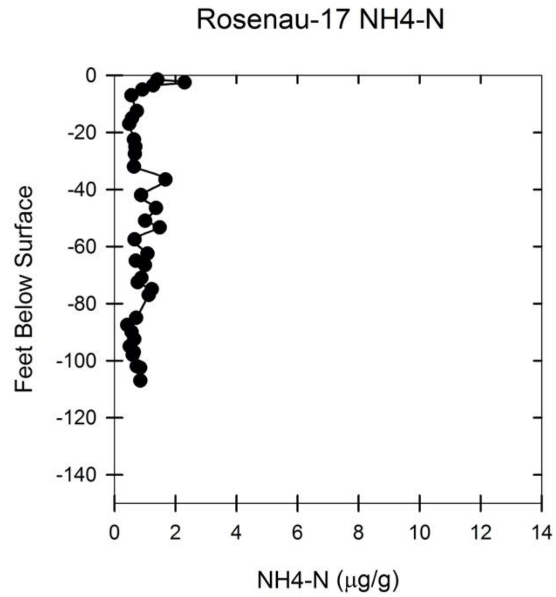
Total NO_3-N Storage = 88 lbs-N/acre

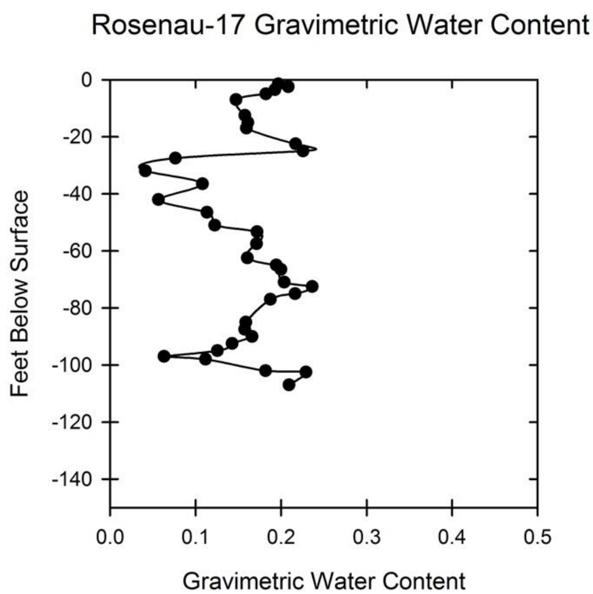
Average Soil NO_3-N = 1.35 µg/g

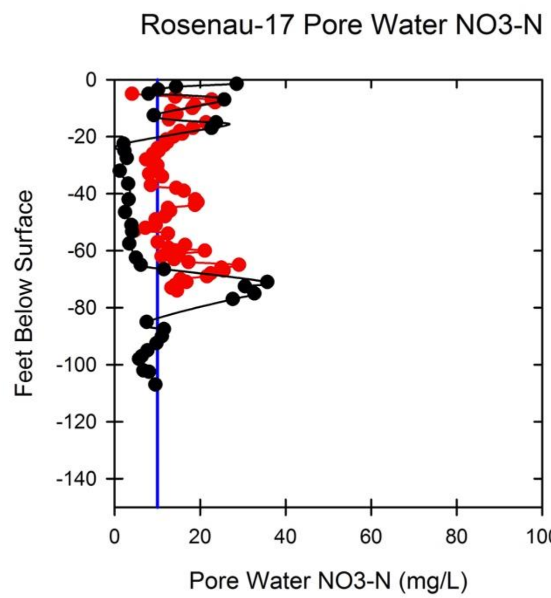
Vertical Blue Line = 10 mg/L MCL

Rosenau-17-19









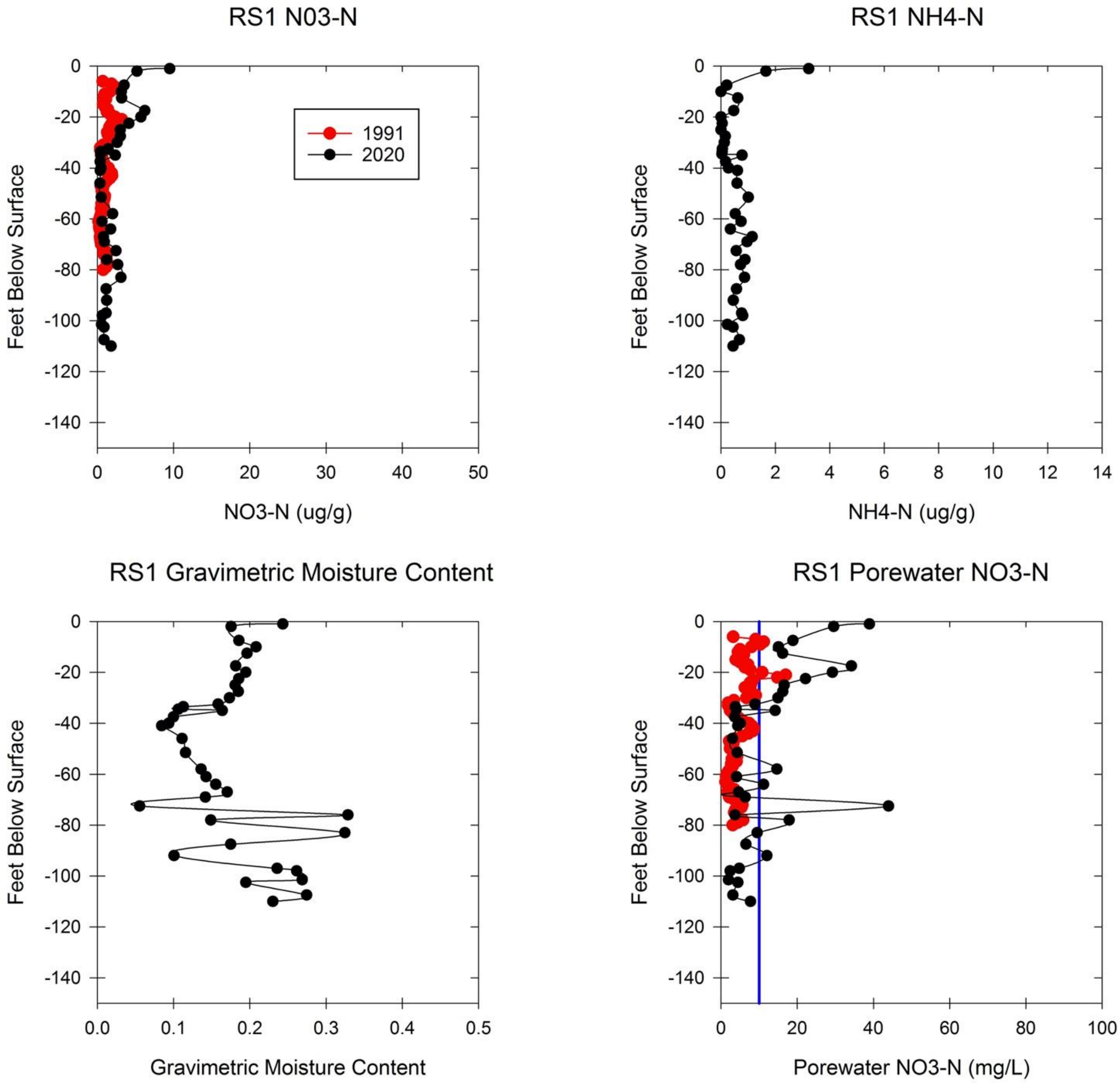
Depth to Water = 110’

Total NO_3-N Storage = 759 lbs-N/acre

Average Soil NO_3-N = 2.08 µg/g

Vertical Blue Line = 10 mg/L MCL

RS-1-20



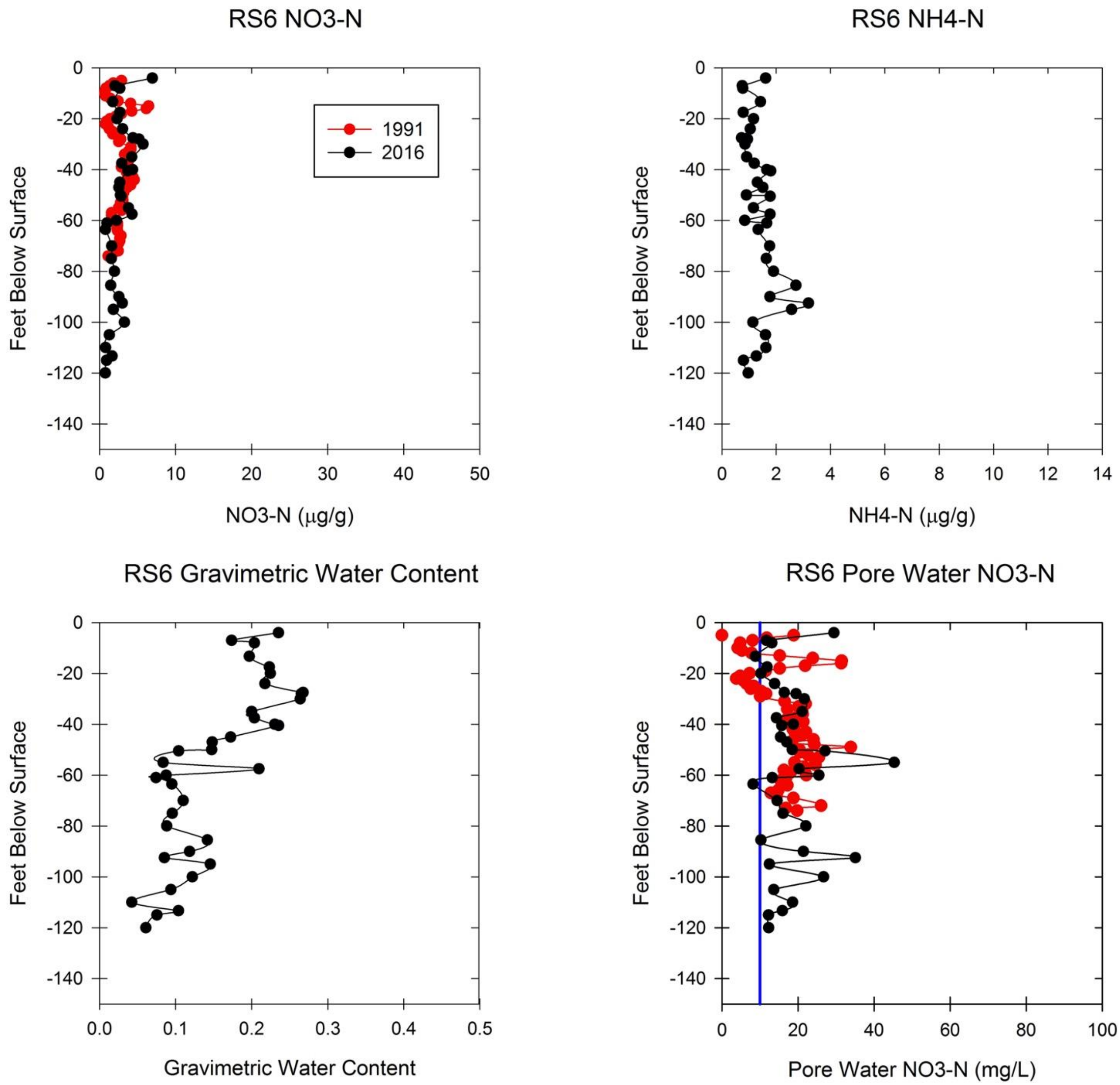
Depth to Water = 108’

Total NO_3-N Storage = 777 lbs-N/acre

Average Soil NO_3-N = 2.14 µg/g

Vertical Blue Line = 10 mg/L MCL

RS-6-17



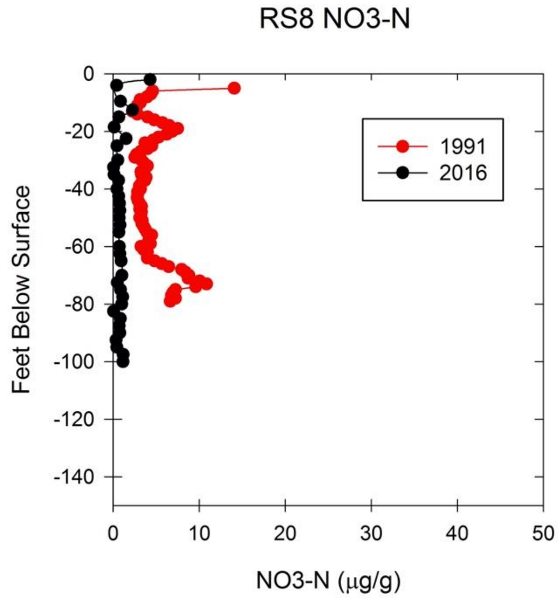
Depth to Water = 120’

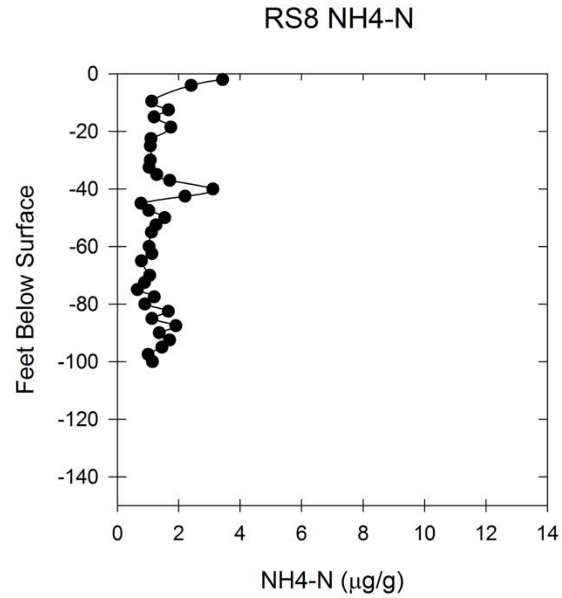
Total NO_3-N Storage = 1,238 lbs-N/acre

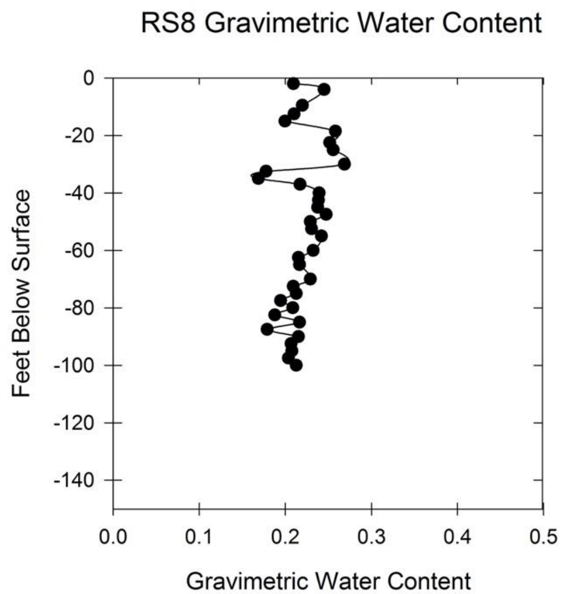
Average Soil NO_3-N = 2.70 µg/g

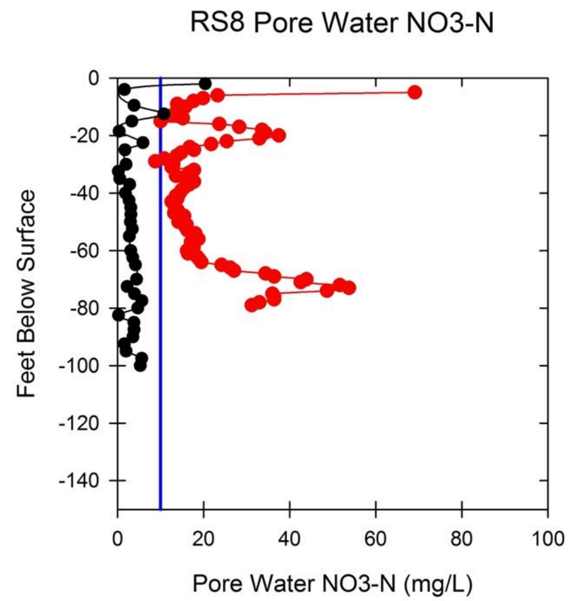
Vertical Blue Line = 10 mg/L MCL

RS-8-17









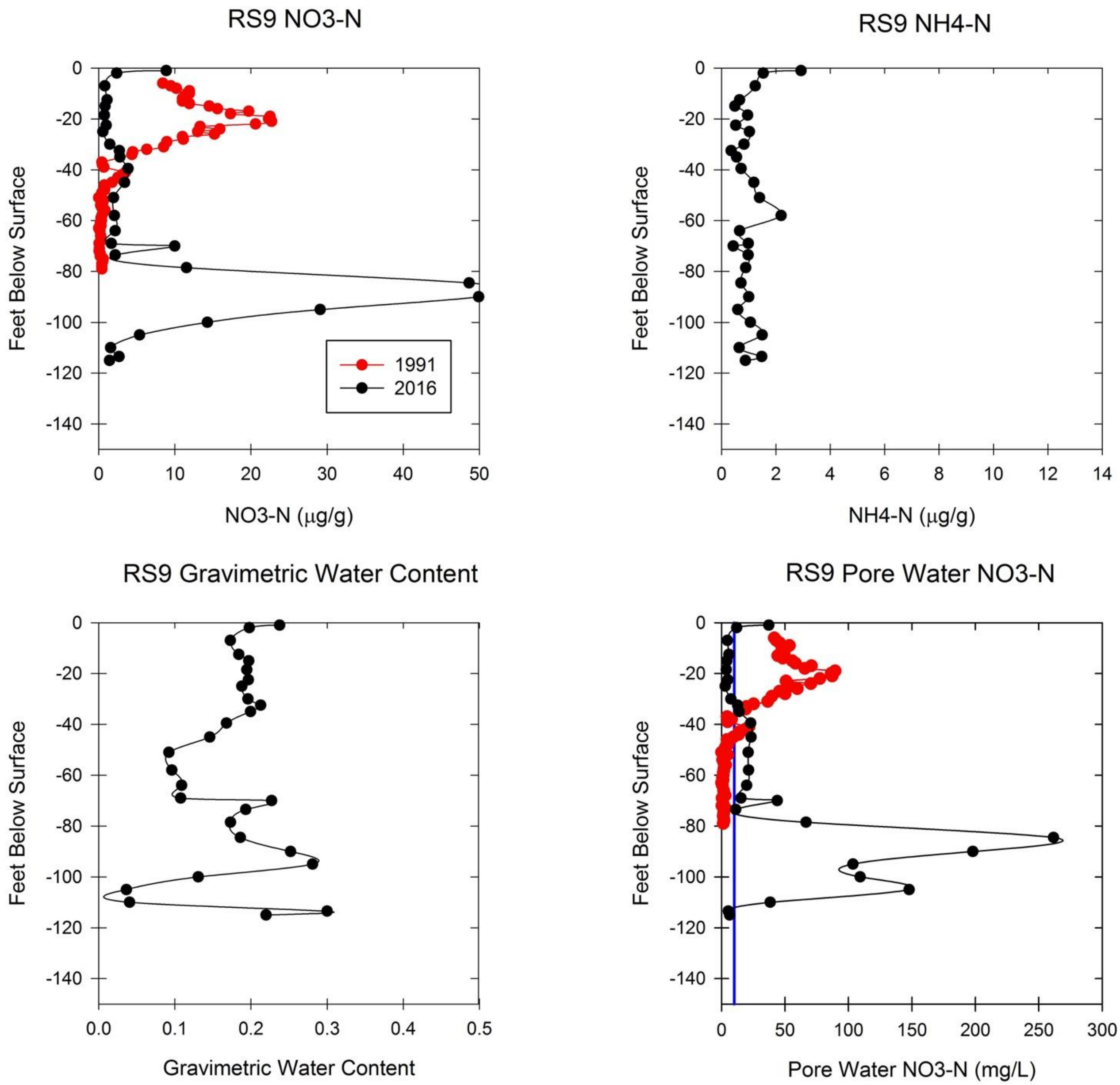
Depth to Water = 100’

Total NO_3-N Storage = 297 lbs-N/acre

Average Soil NO_3-N = 0.82 µg/g

Vertical Blue Line = 10 mg/L MCL

RS-9-17



Depth to Water = 115’

Total NO_3-N Storage = 401 lbs-N/acre

Average Soil NO_3-N = 7.66 µg/g

Vertical Blue Line = 10 mg/L MCL

Appendix 2: Tabulated Results by Core

DH-19-16

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-3.7	1.43	0.19	6.75	3.14	1.99	16.21	12.24	24.48
-5	1.64	0.23	7.44	1.36	0.91	5.98	6.04	7.86
-7.5	1.03	0.21	7.51	1.63	0.60	7.61	4.56	11.40
-9.7	1.17	0.21	7.50	0.39	0.05	1.83	1.24	2.73
-12.5	1.11	0.18	7.68	0.39	0.05	2.20	1.17	3.27
-15	1.17	0.17	7.74	0.13	0.05	0.73	0.40	1.00
-17.5	1.09	0.19	7.77	0.29	0.15	1.51	0.86	2.16
-20	1.23	0.20	7.32	0.60	0.23	3.04	2.01	5.03
-22.5	1.18	0.19	5.43	5.10	0.24	26.96	16.41	41.04
-25	1.02	0.20	4.60	23.51	1.95	116.86	65.19	143.42
-27.5	1.37	0.14	4.66	32.10	1.48	231.06	119.17	119.17
-29.5	1.56	0.10	4.25	17.87	0.19	181.18	75.62	151.24
-35	1.15	0.08	5.01	11.22	0.05	132.56	35.15	87.88
-40	1.50	0.09	6.03	16.00	0.05	180.98	65.20	143.44
-45	1.58	0.08	6.38	17.32	0.05	227.10	74.33	185.83
-45.4	1.06	0.15	6.36	24.68	0.44	162.69	71.09	28.44
-48	1.19	0.15	6.55	15.61	0.05	102.94	50.56	131.46
-49.5	1.68	0.13	6.61	7.62	0.05	60.12	34.90	52.34
-50	1.47	0.21	6.54	9.92	0.36	48.25	39.65	19.83

-52.5	1.41	0.20	6.44	9.89	0.14	48.98	37.89	37.89
-55	1.67	0.20	6.40	10.87	0.55	54.09	49.46	123.64
-57.5	1.25	0.19	6.45	15.28	0.27	80.24	52.09	130.23
-59.4	1.42	0.23	6.41	25.37	0.37	111.76	97.95	186.11
-60.7	1.72	0.20	6.45	45.13	1.68	225.23	211.39	274.81
-63	1.84	0.10	7.01	35.14	3.39	364.40	175.94	87.97
-65	1.97	0.25	6.91	60.02	4.56	240.08	321.83	643.66
-70	1.88	0.05	6.56	19.68	0.90	398.70	100.74	251.85
-75	1.69	0.09	6.60	40.62	0.78	434.75	186.89	467.22
-78	1.39	0.23	6.46	75.80	1.00	335.77	286.72	716.80
-80	1.70	0.18	6.68	84.19	1.36	457.97	389.92	779.84
-80.5	1.30	0.21	6.74	76.43	1.80	370.37	270.71	135.36
-82.5	1.22	0.21	6.78	74.85	1.59	355.64	248.82	497.65
-84	1.27	0.17	6.59	60.54	0.69	350.15	209.36	314.04
-85	1.62	0.09	6.71	30.03	0.55	328.43	132.42	132.42
-88.8	1.24	0.16	6.53	47.70	1.20	290.93	160.36	208.47
-90	1.69	0.06	6.68	21.03	0.18	346.77	96.58	115.90
-94	1.81	0.04	6.66	21.46	0.36	575.45	105.81	158.72

DH-20-16

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1.5	1.68	0.19	5.46	1.66	1.17	8.50	7.55	11.32
-2.5	1.93	0.23	7.24	1.22	0.05	5.40	6.39	6.39

CC

-7.5	1.42	0.23	7.12	5.37	0.05	23.67	20.73	10.37
-10	1.50	0.26	7.13	8.26	0.05	32.34	33.62	84.05
-15	1.70	0.25	4.62	8.69	0.53	34.83	40.23	80.46
-17.5	1.35	0.29	4.00	7.09	2.09	24.17	25.94	12.97
-20	1.28	0.29	4.20	9.71	4.23	33.71	33.81	84.54
-22.5	0.83	0.25	4.34	9.06	6.14	36.14	20.55	51.39
-25	1.25	0.30	4.36	10.67	11.47	35.75	36.32	90.81
-27.5	0.98	0.27	4.37	8.86	8.71	33.32	23.69	59.22
-30	1.35	0.22	4.47	7.85	9.91	34.89	28.79	71.98
-32.5	0.96	0.18	4.74	9.20	7.07	50.03	24.05	60.13
-35	1.27	0.14	5.13	6.22	4.82	42.98	21.41	53.54
-37.5	1.04	0.10	5.65	7.87	3.41	78.49	22.19	55.47
-40	1.52	0.16	6.67	6.43	1.78	40.17	26.50	66.25
-42.5	1.38	0.16	7.01	14.60	1.69	92.64	54.73	136.83
-44.5	1.81	0.18	7.17	18.56	0.05	103.77	91.38	182.76
-47.5	1.54	0.19	7.06	21.02	1.92	113.06	88.01	264.04
-49	1.32	0.19	6.92	30.81	0.53	160.01	110.82	166.22
-50	1.61	0.08	6.91	16.52	0.05	217.66	72.33	72.33
-54.3	1.99	0.11	6.88	23.37	0.39	216.50	126.56	227.80
-55	1.77	0.20	6.85	41.39	1.07	206.07	198.99	139.30
-58.7	1.17	0.17	6.79	65.90	2.17	386.97	209.59	461.09
-60	1.70	0.16	6.74	41.41	0.05	260.90	190.91	248.19

DH-21-16

Total Below Surface (ft)	ρb (g/ml)	ϴg	pH Analysis	NO_3N (ug/g)	NH_4N (ug/g)	Pore Water NO_3N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
-0.5	1.24	0.20	5.60	4.52	5.97	22.87	15.19	7.60
-2	1.28	0.21	6.83	1.72	3.63	8.21	6.02	9.03
-2.5	1.45	0.18	6.76	6.20	5.51	34.95	24.41	12.20
-7.5	1.66	0.20	7.07	7.59	1.80	37.77	34.25	68.50
-13	0.86	0.20	7.19	0.62	2.96	3.11	1.45	2.18
-15	1.05	0.20	7.23	0.40	3.04	2.05	1.15	2.30
-17.5	1.73	0.20	7.16	0.97	2.73	4.73	4.57	4.57
-22.5	1.33	0.18	7.38	1.70	1.48	9.58	6.17	15.42
-27.5	1.83	0.19	7.40	2.70	2.17	14.20	13.47	33.68
-32.5	1.59	0.20	7.43	5.81	2.90	29.57	25.05	62.63
-35	1.21	0.20	7.49	4.54	2.64	22.72	14.87	37.19
-37.5	1.74	0.21	7.46	6.16	3.02	29.15	29.16	72.90
-42	1.13	0.25	7.44	7.95	1.17	31.24	24.43	48.87
-43.5	1.34	0.24	7.38	11.68	2.24	48.35	42.44	63.66
-45	1.60	0.22	7.26	8.30	1.77	38.31	36.08	54.12
-47.5	1.87	0.19	7.36	7.29	1.72	38.17	37.15	37.15
-52.5	1.30	0.22	7.50	9.57	2.58	43.54	33.84	84.59
-54	1.68	0.23	7.45	9.48	2.39	40.45	43.21	64.82
-55	1.68	0.24	7.38	9.28	1.65	38.45	42.39	42.39
-58	1.64	0.25	7.41	9.47	1.34	38.26	42.31	50.77
-60	1.39	0.25	7.27	13.25	1.91	51.99	50.07	100.14

-62.5	1.10	0.25	7.19	17.65	2.50	70.68	52.75	131.87
-65	1.56	0.22	7.28	19.24	1.85	88.33	81.43	203.57
-67.5	1.45	0.26	7.12	13.88	2.61	52.42	54.73	109.46
-70	1.56	0.23	7.03	7.64	0.94	33.17	32.38	80.94
-72.5	1.43	0.25	7.15	3.53	1.23	14.03	13.76	34.39
-75	1.40	0.25	7.13	1.72	1.00	6.87	6.54	16.34
-77.5	1.53	0.24	7.26	1.25	1.05	5.32	5.23	13.06
-80	1.56	0.24	7.21	1.01	1.26	4.24	4.28	10.70
-81.3	1.51	0.19	7.16	0.66	1.35	3.47	2.71	3.52
-83	1.38	0.19	7.38	0.82	1.37	4.21	3.08	5.23
-85	1.54	0.21	7.12	0.75	1.25	3.54	3.15	6.30
-87.5	1.41	0.24	7.05	1.01	1.56	4.20	3.86	9.64
-90	1.90	0.20	7.21	0.11	1.34	0.54	0.56	1.41
-92.5	1.42	0.23	7.28	0.92	1.67	4.06	3.55	8.88
-94.5	1.57	0.22	7.63	0.91	2.27	4.15	3.89	7.77
-96	1.29	0.23	7.51	0.86	2.44	3.71	3.00	4.50
-97	1.59	0.24	7.40	0.96	2.25	3.92	4.16	4.16
-100	1.33	0.18	7.37	0.76	2.24	4.15	2.77	6.92
-105	1.30	0.24	7.34	0.85	5.34	3.55	3.02	7.56
-106	1.65	0.17	7.15	0.67	1.39	3.88	3.03	3.03
-110	1.76	0.15	7.34	0.56	1.53	3.79	2.70	6.75
-112	1.31	0.25	7.43	0.90	2.00	3.57	3.22	6.45
-117.5	1.61	0.23	7.41	0.39	1.60	1.69	1.72	4.29
-120	1.63	0.23	7.47	0.75	2.32	3.22	3.34	8.36

DH-22-2-16

Total Below Surface (ft)	ρb (g/ml)	Θg	pH Analysis	NO_3N (ug/g)	NH_4N (ug/g)	Pore Water NO_3N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
-2	1.56	0.23	6.03	7.07	4.06	31.08	29.98	59.95
-7.5	1.39	0.25	7.18	5.38	1.39	21.60	20.39	50.98
-11.5	1.45	0.23	7.18	4.49	0.97	19.51	17.76	26.65
-17.5	1.47	0.22	7.38	1.41	0.85	6.43	5.65	14.14
-22.5	1.49	0.22	7.52	0.84	0.89	3.79	3.39	8.48
-27.5	1.22	0.25	7.84	1.43	0.81	5.79	4.75	11.87
-30	1.35	0.26	7.81	1.70	1.04	6.53	6.26	15.65
-31	1.57	0.26	7.64	1.51	1.11	5.81	6.44	6.44
-33.5	1.38	0.27	7.66	1.81	1.33	6.84	6.80	17.01
-37	1.47	0.23	7.49	1.50	1.33	6.58	5.97	11.94
-39	1.31	0.19	7.70	1.19	1.01	6.20	4.22	6.32
-41	1.68	0.17	7.66	1.22	0.85	7.02	5.58	11.17
-42	1.68	0.15	7.68	1.02	0.88	6.88	4.66	4.66
-46.5	1.30	0.22	7.56	1.49	1.18	6.84	5.27	7.91
-50	1.63	0.19	7.64	1.74	1.44	9.01	7.69	19.23
-52.5	1.74	0.16	7.71	1.40	1.34	9.02	6.63	3.31
-55	1.86	0.19	7.63	1.28	1.08	6.84	6.50	16.25
-57.5	1.96	0.11	7.52	0.75	0.68	7.03	4.00	10.00
-62.5	1.99	0.07	7.70	0.71	0.74	9.71	3.84	7.67
-67.5	2.00	0.10	7.61	0.81	1.08	8.02	4.39	10.96

-75	1.75	0.09	7.55	0.83	0.87	8.75	3.94	9.84
-77.5	1.72	0.13	7.56	1.00	0.97	7.62	4.66	11.66
-83.5	1.52	0.21	7.46	3.41	1.30	16.23	14.13	21.19
-85	1.52	0.22	7.41	4.34	1.15	20.01	17.98	26.97
-87.5	2.20	0.12	7.35	3.30	1.10	27.68	19.75	49.37
-92.5	1.57	0.05	7.33	2.00	1.22	43.24	8.51	21.27
-97	1.82	0.05	7.28	1.60	1.17	33.14	7.92	15.83
-102	1.58	0.07	7.19	1.52	1.10	21.17	6.52	13.05
-107	1.96	0.08	7.25	1.29	1.49	17.25	6.90	13.81
-111	1.73	0.09	7.45	1.90	2.08	21.16	8.90	8.90

DH-26-19

TotalBelow Surfce (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.44	0.18	7.42	6.97	2.91	38.13	27.33	27.33
-7	1.12	0.15	8.02	2.37	1.36	15.39	7.23	14.46
-12	1.25	0.17	8.00	0.74	1.56	4.50	2.54	5.07
-17.5	1.20	0.18	8.01	1.40	0.09	7.80	4.57	11.44
-20	1.22	0.16	7.95	1.64	0.13	10.06	5.43	13.58
-22.5	1.17	0.17	7.97	2.54	0.03	14.62	8.09	20.23
-25	1.34	0.17	7.91	1.68	0.07	9.96	6.11	15.28
-27.5	1.24	0.18	7.95	1.44	0.00	7.86	4.84	12.09
-30	1.27	0.19	8.03	2.15	0.02	11.24	7.43	18.56
-32.5	1.29	0.19	8.06	1.67	0.10	8.73	5.87	14.67
-35	1.38	0.19	7.88	1.93	0.16	10.12	7.24	18.11

HH

-37.5	1.36	0.19	8.21	1.99	1.50	10.33	7.37	18.43
-40	1.38	0.19	8.06	0.18	0.21	0.96	0.69	1.73
-42.5	1.22	0.18	8.01	2.32	1.80	12.71	7.70	19.24
-45	1.39	0.21	8.18	2.13	1.62	10.21	8.01	20.03
-47.5	1.24	0.19	8.30	0.99	1.85	5.29	3.33	8.32
-50	1.23	0.20	8.14	0.97	1.51	4.79	3.25	8.12
-52.5	1.30	0.19	8.11	1.42	1.18	7.61	5.00	12.51
-55	1.26	0.20	8.19	1.56	1.31	7.84	5.35	13.37
-57.5	1.35	0.21	8.17	1.28	1.46	6.21	4.69	11.73
-60	1.24	0.22	8.09	0.98	1.22	4.42	3.30	8.25
-62.5	1.35	0.24	8.07	1.34	1.41	5.67	4.90	12.26
-65	1.51	0.25	8.06	2.87	1.59	11.52	11.82	29.55
-67	1.18	0.27	8.12	3.40	1.02	12.81	10.92	21.83
-69	1.63	0.20	8.04	3.26	1.43	16.18	14.47	28.95
-70	1.68	0.18	8.02	1.67	0.99	9.24	7.60	7.60
-72.5	1.79	0.06	8.20	0.74	0.73	12.51	3.63	9.07
-77	1.54	0.11	8.49	0.76	0.88	6.66	3.18	6.36

DH-28-17

Total Below Surface (ft)	**ρb (g/ml)**	**Ɵg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1.5	1.28	0.23	6.36	9.13	2.63	39.23	31.80	47.70
-3	1.71	0.22	6.94	6.48	2.52	29.88	30.19	45.29
-7.5	1.46	0.17	7.47	4.62	1.89	26.82	18.29	45.72
-11.5	1.29	0.15	7.65	15.08	1.66	99.36	52.82	79.23

-13.5	1.37	0.17	7.74	13.93	2.02	84.31	51.85	103.71
-17.5	1.41	0.17	7.71	15.56	1.90	90.11	59.70	149.26
-22.5	1.37	0.17	7.96	8.67	1.04	52.11	32.24	80.60
-25	1.09	0.14	8.22	6.66	1.42	46.33	19.76	49.40
-27.5	1.49	0.16	8.04	4.77	1.24	30.51	19.31	48.28
-32.5	1.37	0.16	7.95	3.89	1.30	23.84	14.51	36.28
-35	1.56	0.16	7.95	3.75	1.27	23.63	15.90	39.76
-37.5	1.70	0.16	7.92	4.11	1.21	26.01	18.94	47.35
-42.5	1.17	0.16	7.33	5.98	1.02	36.52	19.08	47.70
-45	1.13	0.17	7.62	5.52	0.85	31.77	16.99	42.49
-47.5	1.63	0.15	7.72	4.41	0.39	30.27	19.53	48.82
-52.5	1.32	0.16	7.63	4.44	0.71	28.14	15.92	39.81
-55	1.39	0.14	7.86	4.77	0.71	35.16	17.96	44.90
-57.5	1.54	0.14	7.73	5.15	0.38	36.72	21.57	53.94
-62.5	1.23	0.19	7.63	8.77	0.30	47.31	29.25	73.13
-65	1.50	0.17	7.74	9.73	0.36	56.04	39.70	99.24
-66.5	1.46	0.21	7.70	10.18	0.47	48.46	40.39	60.59
-71.5	1.34	0.17	7.70	7.48	0.69	43.44	27.17	40.76
-73	1.29	0.17	7.72	5.77	0.74	33.22	20.21	30.31
-74.5	1.52	0.16	7.69	3.82	0.41	24.33	15.80	23.70
-75.3	1.68	0.16	7.84	4.54	0.74	28.20	20.79	16.63
-77	1.68	0.15	7.93	3.36	0.22	22.89	15.34	26.07
-82.5	1.53	0.17	7.49	2.51	1.34	15.18	10.46	26.14
-85	1.83	0.18	7.54	2.37	0.88	12.87	11.79	29.47
-87	1.68	0.08	7.64	1.62	0.68	20.11	7.40	14.79
-91	1.53	0.17	7.72	1.70	0.44	9.81	7.10	7.10

-93	1.64	0.08	7.93	1.00	0.62	12.46	4.45	8.89
-96	1.56	0.13	7.65	1.26	0.82	9.61	5.37	5.37
-98	1.63	0.18	7.74	0.92	0.27	5.08	4.09	8.18
-102.5	1.36	0.17	7.75	1.05	0.39	6.30	3.91	9.77
-105	1.91	0.17	7.85	0.89	0.29	5.32	4.63	11.58
-107.5	1.71	0.17	7.76	1.01	0.66	6.06	4.70	11.74
-111	1.59	0.13	7.98	0.60	0.37	4.55	2.61	2.61
-113.5	1.60	0.13	7.98	0.69	0.37	5.38	2.99	7.48
-117.5	1.89	0.17	7.86	1.00	0.55	5.84	5.15	12.88
-121.5	1.48	0.14	7.47	1.11	0.50	8.01	4.44	6.66
-124	1.24	0.12	7.85	1.13	0.55	9.49	3.79	9.48
-127	1.69	0.15	7.94	1.68	0.50	11.54	7.72	15.44

DH-29-17

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.33	0.18	6.41	4.37	4.61	24.08	15.74	15.74
-2	1.24	0.18	7.07	1.31	2.03	7.38	4.39	4.39
-4	1.12	0.16	7.67	3.00	1.46	19.11	9.18	18.35
-7	0.96	0.18	7.73	4.88	2.02	27.23	12.70	25.41
-10.5	1.34	0.18	7.91	2.83	1.87	15.99	10.31	5.15
-17.5	1.01	0.15	8.15	1.06	1.64	6.97	2.92	7.30
-20	1.23	0.17	8.26	2.12	0.96	12.32	7.08	17.71
-22.5	1.43	0.19	8.26	1.80	0.80	9.73	6.97	17.44

KK

-27.5	1.38	0.17	8.18	5.54	1.10	32.92	20.82	52.06
-30	1.66	0.18	8.14	10.37	1.48	57.53	46.92	117.29
-32.5	1.46	0.17	8.25	6.30	1.30	38.07	25.10	62.75
-37.5	1.42	0.17	8.23	5.48	1.34	31.81	21.20	52.99
-40	1.23	0.17	8.10	3.66	1.29	20.94	12.24	30.59
-42	1.70	0.18	7.44	2.69	1.13	14.64	12.41	24.83
-47.5	1.29	0.16	7.88	3.05	1.16	18.75	10.68	26.70
-50	1.47	0.18	7.70	3.21	0.83	17.75	12.84	32.10
-51.5	1.77	0.18	8.06	4.32	0.92	24.29	20.81	31.22
-57.5	1.19	0.22	7.68	10.74	1.11	49.28	34.69	86.72
-58.2	1.82	0.22	7.58	14.40	0.96	65.39	71.26	49.89
-60	1.67	0.22	7.50	16.65	1.09	77.37	75.46	135.82
-61.5	1.59	0.20	7.55	14.20	1.09	69.93	61.26	91.89
-67.5	1.34	0.23	7.48	10.92	0.77	47.76	39.76	99.41
-70	1.58	0.22	7.43	8.73	0.84	39.97	37.63	94.08
-72.5	1.43	0.24	7.24	7.63	1.06	32.11	29.72	74.30
-75	1.82	0.21	7.19	6.18	0.98	28.75	30.53	76.34
-77.5	1.27	0.26	7.16	4.05	1.02	15.73	13.97	34.93
-79	1.51	0.26	6.61	3.51	1.44	13.41	14.39	21.58
-80	1.53	0.22	6.91	1.94	1.26	8.91	8.09	8.09
-82.5	1.78	0.22	6.85	3.63	1.62	16.37	17.53	43.83
-87.5	1.24	0.29	6.76	10.90	1.33	36.97	36.69	91.72
-89.5	1.28	0.27	6.85	16.48	1.54	60.99	57.37	114.74
-92	1.72	0.12	7.00	8.26	1.12	71.48	38.54	96.34
-97.5	1.36	0.13	7.10	12.61	1.11	96.92	46.71	116.79
-100	1.69	0.15	7.14	11.62	0.87	77.81	53.24	133.10

-101	1.66	0.18	7.11	10.46	0.98	59.30	47.27	47.27
-107.5	1.53	0.24	7.18	8.65	1.06	36.55	35.97	89.92
-112.5	1.71	0.18	7.20	7.94	1.52	44.39	36.91	92.27
-115.5	1.20	0.10	7.18	6.46	2.19	67.82	21.15	10.58
-117.5	1.88	0.18	6.93	10.55	1.04	58.77	53.86	107.72
-120.5	1.64	0.15	7.33	8.42	2.42	56.85	37.59	18.80
-123	1.84	0.19	6.78	9.20	0.98	47.31	45.98	114.96
-125.5	1.35	0.21	6.87	9.59	1.65	45.54	35.33	17.67
-127.5	1.34	0.18	7.16	8.77	1.05	47.79	31.90	63.80
-130	1.66	0.20	7.36	8.55	1.00	42.56	38.59	96.48
-132	1.71	0.11	7.59	5.38	1.15	50.26	24.98	49.96
-137.5	2.02	0.13	7.87	6.48	0.95	49.23	35.66	89.14

DH-30-17

Total Below Surface (ft)	**ρb (g/ml)**	**Ɵg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-2	1.37	0.25	7.06	6.11	1.54	24.29	22.77	45.54
-3.5	1.67	0.23	7.26	6.70	2.19	29.70	30.37	45.55
-9	1.73	0.19	7.26	4.78	1.53	25.70	22.49	33.74
-15	1.39	0.23	7.32	3.27	1.04	14.24	12.32	30.80
-20	1.37	0.26	7.17	7.33	1.19	28.65	27.39	68.48
-22.5	1.14	0.30	7.24	9.37	0.98	30.78	29.14	72.84
-25	1.70	0.22	7.16	10.62	0.84	48.09	49.14	122.86
-30	1.47	0.22	7.04	9.89	0.80	45.00	39.55	-355.97

MM

-32.5	1.47	0.18	6.95	12.20	0.90	68.03	48.90	122.25
-35	1.72	0.19	6.84	10.57	0.70	56.07	49.52	123.79
-38.5	1.55	0.23	6.91	16.95	1.35	73.42	71.45	107.18
-40	1.50	0.25	6.95	23.00	0.95	92.95	93.94	140.91
-42	1.46	0.24	6.97	12.71	1.84	53.02	50.40	100.81
-44	1.59	0.22	6.88	7.11	0.66	32.28	30.84	61.69
-50	1.39	0.27	6.84	6.34	0.81	23.21	23.93	59.82
-51	1.67	0.12	6.84	5.72	0.68	47.67	26.00	26.00
-53	1.53	0.34	6.83	6.27	0.50	18.22	26.07	52.15
-59	2.00	0.04	6.73	4.99	0.52	140.26	27.08	40.62
-65	1.69	0.09	6.85	10.09	0.58	113.42	46.49	116.22

DH-31-16

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.33	0.21	6.25	12.21	1.14	56.94	44.21	44.21
-4.5	1.53	0.19	6.50	5.29	0.68	27.21	22.10	44.20
-5.4	1.56	0.21	6.82	4.54	0.05	21.84	19.33	17.40
-12.5	1.32	0.23	7.06	7.54	0.05	32.96	26.98	53.96
-17.5	1.61	0.20	7.19	5.38	0.05	27.48	23.58	47.16
-23	1.40	0.20	7.09	6.66	0.05	33.19	25.38	76.13
-26	1.61	0.22	7.21	6.57	0.05	29.75	28.82	86.47
-32.5	1.31	0.26	7.27	8.33	0.05	32.66	29.59	73.97
-35	1.53	0.25	7.35	8.79	0.05	34.74	36.59	91.48
-37.5	1.44	0.27	7.14	8.87	0.30	32.44	34.66	52.00

-40	1.54	0.28	7.13	6.84	0.05	24.51	28.57	71.42
-42.5	1.27	0.25	6.95	4.96	0.05	19.59	17.06	42.66
-45	1.70	0.20	6.95	3.12	0.05	15.76	14.46	36.15
-47.5	1.50	0.24	6.94	3.45	0.05	14.47	14.10	35.24
-50	1.62	0.25	6.76	4.24	0.55	16.81	18.63	46.59
-52.5	1.39	0.23	6.94	4.49	0.88	19.44	16.94	42.34
-54	1.43	0.25	6.82	4.82	0.52	19.34	18.75	28.13
-57.5	1.17	0.27	6.80	5.58	1.36	20.52	17.82	44.55
-60	1.74	0.24	6.79	4.73	0.87	19.57	22.35	55.88
-62.5	1.39	0.24	6.83	5.22	0.05	21.63	19.71	49.27
-65	1.68	0.22	6.82	5.38	0.36	24.08	24.55	61.37
-67.5	1.20	0.24	6.82	5.62	0.49	23.65	18.36	45.91
-70	1.47	0.21	6.84	4.91	0.51	23.50	19.61	49.04
-72	1.14	0.18	6.95	3.32	0.05	18.81	10.34	20.67
-73.5	1.48	0.19	6.96	3.70	0.05	19.43	14.89	22.34
-75	1.54	0.24	6.88	3.48	0.05	14.80	14.60	21.90
-77	1.46	0.25	6.94	3.99	0.38	16.26	15.82	31.64
-79	1.76	0.22	6.92	4.02	0.50	18.29	19.21	28.82
-80.5	1.84	0.23	6.79	3.75	0.83	16.56	18.76	28.14
-82.5	1.77	0.24	6.80	3.74	1.48	15.70	17.97	35.93
-84	1.70	0.24	6.86	3.93	0.52	16.69	18.13	27.19
-85	1.59	0.22	6.81	3.12	0.91	14.45	13.51	13.51
-88	1.62	0.20	6.85	2.65	0.42	13.37	11.71	23.41
-90	1.72	0.22	6.90	3.97	1.23	18.17	18.57	37.14
-92.5	1.36	0.22	6.98	3.25	0.54	14.73	12.03	30.08
-94	1.86	0.21	6.89	3.50	0.76	16.89	17.74	26.60

-95	1.90	0.23	6.91	3.42	1.01	15.11	17.66	17.66
-97	1.73	0.22	6.27	3.05	0.55	13.69	14.35	28.70
-99	1.69	0.20	6.67	3.93	1.19	19.24	18.08	72.32
-101	1.49	0.22	6.78	3.76	1.33	17.17	15.25	30.50
-102.5	1.49	0.23	6.89	3.87	0.05	16.61	15.63	23.44
-104	1.58	0.26	6.94	4.00	0.35	15.58	17.19	25.79
-105	1.53	0.25	7.03	4.50	1.11	18.00	18.68	18.68
-107.5	1.59	0.22	7.12	3.76	0.97	16.89	16.28	24.42
-109	1.89	0.23	7.23	4.09	0.39	17.56	20.99	31.48
-110	1.82	0.17	7.30	3.02	0.05	18.21	14.94	14.94

DH-32-16

Total Below Surface (ft)	**ρb (g/ml)**	**Ɵg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-5	1.17	0.28	6.49	2.25	5.09	8.08	7.17	10.04
-8	1.30	0.24	7.19	1.58	0.81	6.47	5.58	11.15
-10	1.33	0.26	7.15	1.90	1.02	7.26	6.87	13.74
-15	1.66	0.23	7.08	0.67	0.80	2.93	3.01	5.42
-17.5	1.10	0.26	7.25	0.65	0.55	2.54	1.95	4.87
-20	1.22	0.24	7.23	0.37	0.68	1.53	1.23	3.08
-23.6	1.16	0.25	7.25	1.06	1.12	4.19	3.34	4.67
-25	1.17	0.26	7.16	1.10	0.71	4.22	3.49	4.88
-27.1	1.09	0.25	7.19	1.07	0.92	4.32	3.16	6.63
-28.6	1.39	0.11	7.08	0.66	1.32	6.01	2.49	3.74
-30	1.29	0.24	6.95	0.29	0.86	1.25	1.03	1.44

-32.2	1.40	0.16	6.46	0.27	0.95	1.71	1.01	1.12
-32.9	1.40	0.09	6.81	0.29	0.70	3.31	1.11	0.77
-33.8	1.58	0.11	6.85	0.56	1.67	4.92	2.40	2.16
-35	1.78	0.09	6.73	0.13	0.85	1.44	4.83	5.80
-40	1.59	0.07	6.87	0.29	0.57	4.44	1.25	3.13
-43.7	1.77	0.14	6.99	0.26	0.69	1.78	1.24	1.49
-45	1.32	0.14	7.01	0.35	0.89	2.43	1.26	1.64
-49	2.26	0.15	7.13	0.35	0.88	2.33	2.13	3.20
-50	1.75	0.11	7.17	0.25	0.80	2.22	1.17	1.17
-55	1.69	0.07	7.19	0.13	0.75	1.80	0.57	1.44
-59.3	1.90	0.06	7.24	0.13	0.55	2.16	0.65	1.29
-60	2.08	0.10	7.12	0.36	0.75	3.72	2.04	1.43
-63	1.66	0.10	7.15	0.39	1.21	4.08	1.78	0.89
-63.2	1.46	0.24	5.92	0.99	3.56	4.12	3.93	0.79
-65	1.56	0.05	7.11	0.13	0.87	2.28	0.53	0.95
-70	1.65	0.04	7.30	0.19	0.55	4.62	0.86	2.14
-75	1.87	0.07	7.26	0.46	0.99	6.56	2.34	5.84
-80	1.51	0.08	7.34	0.44	0.76	5.25	1.83	4.57
-85	1.77	0.19	7.38	1.64	0.63	8.70	7.89	19.72

DH-36-16

Total Below Surface (ft)	**ρb (g/ml)**	**Ɵg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.27	0.26	6.16	5.56	1.86	21.64	19.14	19.14
-2	1.60	0.23	5.93	1.45	2.44	6.19	6.33	6.33

-10	1.58	0.22	6.61	0.47	1.44	2.17	2.03	4.06
-12.5	1.61	0.25	7.04	0.67	0.29	2.69	2.96	2.96
-17	1.23	0.25	7.12	2.02	0.05	8.03	6.76	13.52
-19	1.43	0.27	7.10	1.96	0.05	7.21	7.65	15.29
-20	1.48	0.24	7.09	1.33	0.05	5.56	5.36	5.36
-22.5	1.26	0.27	7.03	1.39	0.05	5.19	4.78	7.16
-25	1.55	0.27	7.11	0.93	0.05	3.49	3.94	9.84
-26	1.20	0.31	7.14	1.95	0.10	6.35	6.39	6.39
-28	1.27	0.31	7.05	2.25	0.33	7.26	7.81	15.61
-30	1.35	0.31	7.01	1.88	0.11	6.05	6.93	13.86
-32.5	1.46	0.31	6.57	2.81	1.15	9.20	11.16	27.90
-34	1.49	0.29	6.41	2.67	2.54	9.15	10.79	16.19
-35.2	1.55	0.29	7.27	0.44	2.24	1.53	1.86	2.24
-36.5	1.25	0.39	6.83	0.26	8.46	0.68	0.89	1.16
-39	1.43	0.25	6.20	0.57	7.23	2.30	2.22	5.56
-41	1.41	0.23	6.02	3.74	1.22	16.33	14.37	28.74
-43.8	1.63	0.23	5.39	4.96	0.78	21.72	22.03	28.63
-45	2.00	0.17	5.31	4.25	0.25	25.71	23.18	27.81
-47.5	1.48	0.22	5.84	5.59	0.05	25.55	22.54	18.03
-49.5	1.65	0.18	5.91	3.92	0.05	22.27	17.57	35.13
-50.5	1.75	0.13	6.34	2.39	1.71	18.84	11.40	11.40
-52.5	1.61	0.12	6.12	2.95	0.07	25.04	12.93	25.86
-56	1.41	0.24	6.06	3.53	0.04	14.59	13.53	13.53
-57.5	1.53	0.25	6.22	3.85	0.42	15.10	15.96	23.94
-60	1.64	0.25	6.33	3.13	0.47	12.67	13.95	27.91
-62.5	1.42	0.07	6.47	1.53	0.39	21.03	5.90	11.80

RR

-67.5	1.30	0.24	6.28	5.85	0.45	24.41	20.67	51.68
-69	1.41	0.23	6.30	6.03	0.68	26.50	23.19	34.78
-70	1.60	0.20	6.39	4.59	0.27	22.39	19.93	19.93
-72.5	1.59	0.25	6.44	5.50	0.16	21.64	23.74	23.74
-74	1.62	0.22	6.53	5.08	0.08	23.29	22.35	33.53
-75	1.87	0.16	6.40	4.79	0.98	30.18	24.30	24.30
-77.5	1.60	0.06	6.42	1.99	0.05	34.51	8.66	17.33
-82.5	1.45	0.09	6.50	3.01	0.05	31.99	11.88	29.71
-87.5	1.65	0.09	6.43	3.14	0.05	33.78	14.09	35.21
-91	1.98	0.06	6.66	2.84	0.36	44.82	15.25	15.25
-92.5	1.33	0.04	6.70	2.27	0.05	52.31	8.20	12.30
-96.5	1.15	0.28	6.55	7.08	0.33	25.47	22.07	33.11
-97.5	1.55	0.09	6.66	4.10	0.42	43.67	17.28	17.28
-102	1.64	0.04	6.88	1.17	0.05	32.32	5.21	10.43
-106	1.39	0.04	7.22	0.77	0.60	18.15	2.93	2.93
-107.5	1.48	0.07	7.04	0.91	0.05	13.29	3.68	5.52
-111.5	1.68	0.17	6.98	3.09	1.25	18.30	14.07	21.11
-112.5	2.10	0.06	7.12	0.89	0.05	16.17	5.09	5.09
-117.5	1.43	0.02	7.27	0.61	0.05	27.88	2.36	5.90
-122.5	1.71	0.06	7.15	0.58	0.05	9.31	2.68	6.71

DH-37-18

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.70	0.23	7.47	3.22	1.20	13.77	14.85	14.85

SS

-6.5	1.41	0.18	8.11	1.20	1.05	6.85	4.60	6.91
-7.5	1.47	0.24	7.89	1.36	1.47	5.57	5.45	5.45
-11.3	1.41	0.19	7.54	0.96	1.20	5.10	3.69	4.79
-17.5	1.12	0.16	8.38	1.22	0.69	7.79	3.70	9.26
-19	1.27	0.20	8.23	1.17	0.67	5.86	4.02	6.04
-20.5	1.22	0.22	8.22	1.57	0.46	7.12	5.22	7.83
-21.3	1.36	0.26	8.27	1.40	0.91	5.28	5.18	4.14
-27	1.28	0.28	8.12	1.19	0.78	4.22	4.13	8.26
-29	1.07	0.35	8.04	1.12	1.25	3.21	3.25	6.51
-30	1.01	0.35	7.85	1.73	1.00	4.88	4.75	4.75
-31.8	1.57	0.25	7.74	1.67	1.56	6.71	7.10	12.79
-37.5	1.33	0.33	7.79	1.61	1.30	4.81	5.80	14.50
-40	1.33	0.28	7.59	1.56	1.51	5.49	5.64	14.11
-45	1.23	0.35	7.54	1.56	1.27	4.43	5.22	11.48
-47.5	1.24	0.27	7.93	1.44	0.70	5.28	4.87	12.17
-50	1.37	0.27	7.89	1.46	1.14	5.44	5.44	13.60

DH-38-19

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.28	0.26	6.84	5.59	2.12	21.37	19.41	19.41
-2	1.14	0.13	7.66	0.99	1.60	7.60	3.07	3.07
-5	1.10	0.14	8.15	0.58	1.28	4.16	1.72	4.29
-7.5	1.03	0.19	8.20	0.99	0.97	5.22	2.77	6.93
-9.5	1.31	0.18	8.27	1.16	1.04	6.51	4.12	8.24

-11.5	1.41	0.22	8.00	2.65	1.19	12.00	10.16	20.32
-12	1.57	0.19	8.12	3.73	1.20	19.88	15.87	7.94
-17	1.18	0.22	8.17	3.84	1.53	17.18	12.27	24.54
-19	1.33	0.31	8.22	3.91	1.46	12.46	14.11	28.21
-22.5	1.25	0.12	7.88	2.29	0.75	19.51	7.79	19.48
-25	1.02	0.26	8.05	1.86	1.07	7.12	5.15	12.88
-27	1.33	0.19	7.98	1.26	0.76	6.50	4.53	9.07
-29.5	1.18	0.14	8.23	1.26	0.60	8.72	4.02	10.06
-32	1.28	0.15	8.09	1.19	0.84	8.09	4.11	8.23
-34.5	0.93	0.11	7.96	1.38	0.93	12.18	3.48	8.71
-37	0.99	0.27	7.77	2.10	0.65	7.70	5.65	11.29
-38	1.17	0.13	8.02	1.34	0.64	10.38	4.25	4.25
-40	1.08	0.22	8.05	1.84	0.88	8.47	5.40	10.80
-41	1.08	0.28	7.92	1.95	0.77	7.08	5.75	5.75
-42.5	1.15	0.28	8.14	1.66	0.71	6.01	5.18	7.78
-45	1.10	0.20	7.98	1.40	0.62	6.82	4.19	10.48
-47.5	1.39	0.17	8.20	2.34	0.68	13.99	8.89	22.23
-50	1.53	0.24	8.36	2.38	0.78	9.75	9.92	24.80
-51.5	1.18	0.16	8.10	1.73	0.62	10.98	5.57	8.35
-53	1.46	0.23	8.17	1.73	0.63	7.50	6.89	10.33
-57	1.24	0.16	8.16	1.31	0.80	7.99	4.40	8.80
-58	1.57	0.28	8.38	2.80	0.74	10.11	11.95	11.95
-62	1.39	0.10	8.49	0.82	0.34	8.59	3.10	6.19
-67.5	1.41	0.15	8.51	3.56	0.51	23.71	13.62	34.06

DH-39-19

Total Below Surface (ft)	ρb (g/ml)	ϴg	pH Analysis	NO_3N (ug/g)	NH_4N (ug/g)	Pore Water NO_3N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
-1.5	1.12	0.12	6.74	6.73	1.36	55.42	20.45	30.68
-3	1.10	0.13	7.46	0.93	1.86	7.19	2.81	4.21
-7.5	1.18	0.10	8.30	1.43	0.80	13.95	4.58	11.46
-11	1.09	0.09	8.24	1.23	0.90	13.54	3.65	3.65
-13.5	1.15	0.13	8.07	0.91	0.74	7.02	2.85	7.13
-16.5	1.00	0.13	8.21	2.69	0.74	20.81	7.32	10.99
-18	1.20	0.16	8.20	3.31	0.58	20.77	10.76	16.14
-22	1.01	0.15	8.22	3.51	1.07	23.00	9.61	19.21
-27.5	1.17	0.14	8.08	2.07	0.82	14.62	6.58	16.46
-30	1.12	0.15	8.16	1.68	0.71	11.26	5.13	12.82
-32.5	1.30	0.14	8.14	1.80	0.99	12.55	6.37	15.92
-35	1.21	0.14	8.05	2.00	0.65	14.05	6.58	16.44
-37.5	1.42	0.16	8.26	1.55	0.65	10.00	6.00	14.99
-40	1.42	0.14	8.32	1.56	0.83	10.75	6.00	14.99
-42	1.26	0.14	8.46	1.30	1.65	9.34	4.45	8.91
-44	1.52	0.12	8.56	0.82	0.63	6.91	3.38	6.76
-47.5	1.44	0.13	8.39	1.34	1.27	10.56	5.25	13.12
-52.5	1.18	0.13	8.39	1.36	1.38	10.22	4.38	10.95

-55	1.17	0.14	8.31	1.27	0.85	9.16	4.04	10.11
-56.5	1.05	0.16	8.24	1.55	2.33	9.56	4.43	6.64
-57.5	1.68	0.17	8.26	1.55	1.54	9.29	7.05	7.05
-62.5	1.05	0.16	8.19	1.91	0.75	12.02	5.48	13.70
-65	1.29	0.18	8.29	2.11	0.77	11.64	7.44	18.60
-67.5	1.32	0.17	8.20	2.33	0.73	13.86	8.32	20.81
-70	1.35	0.17	8.21	4.51	0.58	26.57	16.52	41.29
-72.5	1.19	0.17	8.21	8.07	2.18	47.43	26.18	65.46
-75	1.23	0.18	8.13	7.39	1.06	41.58	24.62	61.55
-77.5	1.36	0.17	8.28	6.13	1.58	36.32	22.67	56.68
-80	1.33	0.17	8.18	13.50	1.02	80.84	48.91	122.27
-82.5	1.52	0.20	8.28	4.44	1.16	22.12	18.37	45.92
-85	1.52	0.19	8.26	4.32	1.00	22.81	17.82	44.55
-87.5	1.55	0.09	8.44	3.17	1.07	35.51	13.37	33.43
-92	1.33	0.10	8.41	3.52	0.92	34.43	12.75	25.50
-93.5	1.68	0.19	8.31	3.44	1.01	18.21	15.72	23.59
-96	1.28	0.19	8.35	4.57	1.13	23.56	15.96	15.96
-97.5	1.50	0.18	8.36	4.52	0.69	24.78	18.48	27.72
-101	1.47	0.16	8.50	6.06	0.88	36.80	24.30	24.30
-102.5	1.73	0.15	8.41	5.74	0.96	38.01	26.91	40.36
-107.5	1.26	0.28	8.03	5.14	1.18	18.41	17.63	44.08
-110	1.52	0.27	8.05	6.13	1.19	22.65	25.26	63.15

DH-40-18

Total Below	**ρb (g/ml)**	**Ѳg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**

Surface (ft)								
-1	1.32	0.19	7.89	6.98	2.13	37.71	25.00	25.00
-2	1.22	0.20	7.21	3.03	2.49	15.42	10.03	10.03
-3	1.22	0.20	7.20	5.76	3.05	28.40	19.09	19.09
-3.8	1.53	0.22	7.39	2.70	2.54	12.04	11.21	8.97
-12	1.16	0.11	7.58	10.29	1.38	97.30	32.58	65.15
-16.5	1.33	0.16	7.74	2.63	1.10	16.79	9.54	14.30
-17	1.62	0.16	7.83	1.13	0.63	7.00	4.97	2.48
-22.5	1.27	0.16	7.77	1.61	0.81	9.92	5.56	13.90
-25	1.15	0.16	7.79	3.83	0.83	24.69	11.92	29.81
-27.3	1.69	0.16	7.77	7.02	0.85	43.09	32.22	74.10
-31.9	1.49	0.16	7.84	1.71	0.82	10.56	6.95	13.21
-37.5	1.27	0.18	7.85	4.18	0.86	23.82	14.41	36.03
-40	1.84	0.19	7.82	11.75	1.12	60.38	58.66	146.64
-42	1.54	0.18	7.76	14.27	0.85	78.12	59.74	119.47
-47.5	1.19	0.17	7.80	5.36	0.79	31.84	17.39	43.48
-50	1.40	0.16	7.83	3.24	1.15	20.01	12.34	30.85
-52.5	1.38	0.21	7.91	11.31	0.74	54.31	42.30	105.75
-55	1.35	0.18	7.84	7.24	1.06	40.68	26.53	66.32
-56.8	1.24	0.17	8.09	0.30	0.46	1.72	0.99	1.79
-61	1.72	0.12	8.24	0.85	0.68	6.89	4.00	4.00
-62.1	1.33	0.14	8.20	0.52	1.30	3.67	1.89	2.07
-66.3	1.77	0.11	7.86	1.17	0.82	10.74	5.61	7.29
-67.3	1.64	0.15	7.90	1.28	0.43	8.72	5.71	5.71
-73	1.51	0.14	7.94	0.74	0.72	5.33	3.03	9.08
-77	1.20	0.21	7.84	1.10	0.71	5.13	3.60	7.21

-78	1.48	0.20	7.72	1.08	0.54	5.28	4.33	4.33

DH-41-16

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1.2	1.28	0.33	6.70	9.97	1.28	30.51	34.62	41.55
-2.5	1.62	0.20	6.84	2.69	1.36	13.22	11.87	15.43
-6	1.53	0.24	7.55	1.57	1.88	6.60	6.52	6.52
-12.5	1.33	0.18	7.83	1.31	1.07	7.47	4.72	11.81
-16	1.66	0.20	7.96	1.01	1.70	5.02	4.57	4.57
-21.5	1.35	0.18	7.99	1.23	0.79	6.82	4.49	6.73
-23.5	0.98	0.31	7.84	1.21	0.86	3.85	3.22	6.43
-27.5	1.34	0.21	7.71	1.41	1.09	6.73	5.16	12.89
-28.5	1.50	0.20	7.74	1.56	0.65	7.78	6.36	6.36
-31.3	1.36	0.16	7.95	1.07	1.33	6.52	3.96	5.15
-32.5	1.16	0.22	7.76	0.69	0.95	3.15	2.19	2.63
-35	1.12	0.28	7.65	1.38	0.52	4.94	4.21	10.52
-37	1.54	0.17	7.83	1.27	0.60	7.37	5.31	10.62
-37	1.15	0.22	7.94	0.67	0.91	3.06	2.11	4.23
-39.5	1.29	0.29	7.86	0.68	1.22	2.37	2.39	5.98
-47.5	1.36	0.29	7.95	1.10	0.44	3.77	4.08	10.21
-52.5	1.10	0.30	7.74	1.68	0.80	5.61	5.05	12.62

-55	1.25	0.32	7.82	1.90	0.59	5.94	6.45	16.12
-57.5	1.40	0.26	7.66	2.09	0.47	7.94	7.99	19.98
-61.1	1.15	0.27	7.73	1.63	0.82	6.01	5.09	5.60
-63.6	1.46	0.19	7.87	1.54	0.53	7.90	6.10	15.26
-67	1.53	0.26	7.89	1.22	0.81	4.75	5.06	10.12
-72.5	1.72	0.13	8.22	0.82	0.43	6.44	3.82	9.54
-76.1	1.45	0.32	7.98	3.33	0.50	10.51	13.16	14.48
-76.8	1.81	0.16	7.96	0.88	0.93	5.46	4.36	3.05
-80.7	1.49	0.14	7.96	1.14	1.08	8.05	4.64	3.25
-83	1.87	0.07	8.10	0.89	0.90	13.47	4.53	10.42
-86.3	1.88	0.09	7.89	2.01	1.09	21.88	10.25	13.32
-87.3	1.88	0.15	7.93	2.01	1.16	13.04	10.31	10.31
-90.6	1.44	0.09	8.01	0.96	1.56	11.00	3.78	2.27
-93.1	1.60	0.13	8.03	0.89	0.76	6.85	3.88	9.71
-97	1.48	0.22	7.94	1.92	1.22	8.64	7.72	15.43
-101.6	1.81	0.05	8.04	0.99	0.73	21.59	4.87	7.79
-106.8	1.96	0.05	8.14	0.85	0.84	18.76	4.53	8.15
-112.2	1.84	0.17	8.05	1.89	0.67	11.20	9.46	20.82

DH-47-16

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-3.7	1.09	0.23	6.36	12.63	3.94	54.32	37.26	44.71
-5	1.71	0.20	6.38	1.19	1.80	5.80	5.53	7.19
-8.8	0.90	0.20	7.16	0.77	0.16	3.97	1.90	2.47

-10	1.43	0.21	7.24	0.76	0.23	3.65	2.95	3.54
-12.5	1.10	0.20	7.20	2.15	0.28	10.91	6.41	16.03
-15	1.11	0.19	7.26	0.86	0.15	4.47	2.59	6.47
-18	1.21	0.20	7.26	0.94	0.05	4.77	3.11	3.11
-20	1.30	0.22	7.26	1.99	0.05	9.00	7.03	14.07
-21.5	1.09	0.27	7.21	3.67	0.36	13.49	10.82	16.23
-23.5	1.19	0.21	7.12	2.97	0.05	14.06	9.60	19.20
-25	1.66	0.17	7.06	2.53	0.05	15.09	11.43	17.14
-28	1.16	0.16	7.04	3.32	0.05	20.67	10.42	20.84
-30	1.79	0.08	6.31	1.61	0.05	19.22	7.83	15.66
-35	1.53	0.08	7.45	1.17	0.05	14.37	4.85	11.64
-39.2	1.28	0.06	7.34	1.06	0.05	16.52	3.71	6.30
-40	1.80	0.17	7.33	1.97	0.52	11.91	9.67	7.74
-43.7	1.52	0.11	6.63	0.57	0.14	5.39	2.36	2.83
-45	1.69	0.15	8.14	0.56	0.24	3.67	2.59	3.37
-48.7	1.28	0.19	7.51	0.52	0.05	2.72	1.79	2.15
-50	1.74	0.18	7.67	0.57	0.05	3.13	2.72	3.53
-53.6	1.88	0.10	7.70	0.50	0.05	4.90	2.58	2.84
-55	1.87	0.18	7.54	0.73	0.05	4.08	3.70	5.18
-57.7	1.21	0.17	7.43	0.94	0.13	5.48	3.07	7.68
-59	1.28	0.19	7.50	1.05	0.90	5.53	3.66	4.75
-60	1.64	0.15	7.50	0.89	0.12	5.78	3.99	3.99
-62.5	1.31	0.06	7.38	0.74	0.35	12.48	2.62	2.36
-64	1.50	0.07	7.48	0.59	0.05	8.75	2.40	3.59
-65.4	1.78	0.13	7.55	1.02	0.49	7.73	4.95	6.94
-66.2	1.44	0.11	7.37	1.79	0.07	15.99	7.01	5.61

AAA

-67.5	1.32	0.09	7.41	1.67	0.33	19.38	5.97	7.76
-69.5	1.51	0.17	7.36	2.40	0.05	13.99	9.87	19.73
-70.5	1.46	0.08	7.23	1.29	0.13	16.74	5.14	5.14
-72.5	1.54	0.05	7.49	1.06	0.34	20.51	4.45	8.90
-80	1.63	0.06	7.34	1.53	0.30	26.73	6.76	15.56
-85	1.77	0.06	7.34	1.06	0.05	18.64	5.11	12.78

DH-48-16

Total Below Surface (ft)	**ρb (g/ml)**	**Ɵg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1.5	1.33	0.22	5.69	3.14	2.58	14.26	11.34	17.01
-3	1.02	0.23	6.34	2.54	2.57	10.96	7.06	10.59
-4	1.45	0.20	6.78	2.46	1.68	12.05	9.68	9.68
-5	1.30	0.22	7.10	1.88	0.89	8.55	6.65	6.65
-7	1.10	0.25	7.42	4.71	0.54	18.83	14.03	28.05
-10	1.13	0.24	7.40	2.88	0.75	12.08	8.81	22.02
-15	1.39	0.21	7.62	9.58	1.07	44.93	36.33	90.82
-17.5	1.13	0.22	7.66	7.52	0.93	33.94	23.02	57.55
-20	1.43	0.24	7.64	5.67	0.88	23.38	22.12	55.31
-22.5	1.17	0.24	7.63	5.08	0.96	20.77	16.15	40.37
-23.8	1.11	0.22	7.54	4.57	1.79	21.11	13.75	17.87
-26.3	1.43	0.21	7.50	3.95	1.98	19.27	15.37	38.41
-27.5	1.23	0.17	7.46	3.20	1.81	18.91	10.72	12.87
-30	1.43	0.11	7.57	2.81	1.27	24.91	10.95	27.37
-32.5	1.51	0.09	7.58	2.77	1.11	29.76	11.39	28.48

-35	1.60	0.23	7.46	6.52	1.42	28.83	28.34	70.86
-35	1.63	0.10	7.52	2.32	0.05	23.24	10.28	25.70
-40	1.48	0.20	7.16	5.30	0.52	26.76	21.39	53.48
-42.5	1.24	0.18	7.02	4.66	0.72	25.27	15.78	39.45
-44.3	1.34	0.14	6.73	3.51	0.05	24.27	12.83	23.10
-45	1.61	0.17	6.91	4.21	0.58	25.51	18.49	12.95
-50	1.48	0.14	6.75	2.40	0.05	17.39	9.70	29.10
-55	1.89	0.12	6.64	2.51	0.05	21.13	12.90	32.24
-60	1.66	0.11	6.97	2.80	0.60	26.30	12.64	31.61
-64	1.33	0.07	6.83	1.76	0.05	24.05	6.36	15.89
-65	1.87	0.12	7.01	1.99	0.05	16.12	10.14	10.14
-66.7	1.41	0.12	6.99	2.86	0.05	24.51	10.95	18.61
-67.5	1.74	0.25	7.00	3.95	0.73	16.09	18.71	14.97
-69	1.73	0.17	7.04	3.19	0.56	18.29	14.97	22.45
-70	2.06	0.15	7.13	2.83	1.22	18.88	15.91	15.91
-73	1.39	0.11	6.95	1.44	0.49	12.73	5.44	5.44
-75	2.00	0.18	7.05	1.85	0.05	10.44	10.05	20.10

DH-49-17

Total Below Surface (ft)	**ρb (g/ml)**	**Ɵg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-0.9	1.45	0.22	6.50	7.02	2.75	32.51	27.69	24.92
-1.8	1.63	0.24	5.82	2.12	1.93	8.89	9.42	8.48
-7.5	1.22	0.18	6.12	1.02	1.67	5.70	3.39	3.39
-10	1.34	0.20	6.97	3.84	1.06	19.18	13.95	34.88

-13.9	1.23	0.19	7.28	4.57	1.96	23.59	15.28	6.11
-15	1.45	0.21	7.30	4.92	1.04	23.13	19.39	21.33
-18.7	1.18	0.25	7.29	3.03	0.94	12.04	9.72	13.60
-20	1.60	0.23	7.31	2.33	1.15	9.97	10.15	13.20
-25	1.67	0.22	7.28	1.36	1.68	6.09	6.20	12.39
-28	1.62	0.20	7.14	0.26	1.34	1.32	1.16	1.16
-30	1.52	0.18	7.06	1.36	1.54	7.59	5.64	11.29
-32.6	1.42	0.15	6.80	1.81	2.77	11.86	6.99	4.19
-35	1.51	0.21	7.42	1.18	2.00	5.64	4.83	11.58
-37.5	1.11	0.14	7.75	1.01	1.77	7.06	3.06	3.06
-38.5	1.50	0.11	7.92	0.75	1.13	6.63	3.05	3.05
-40	1.49	0.22	7.77	1.76	2.30	8.01	7.14	10.71
-42.5	1.56	0.20	7.56	2.86	2.56	14.26	12.15	12.15
-45	1.86	0.20	7.50	3.52	1.89	17.57	17.83	44.57
-48	1.01	0.17	7.57	2.66	1.46	15.55	7.30	9.50
-50	1.35	0.08	7.70	1.79	1.24	21.63	6.58	13.16
-55	1.53	0.05	7.68	2.13	1.94	43.24	8.85	17.71
-60	1.61	0.09	7.43	2.37	0.77	27.16	10.35	20.70
-65	1.81	0.11	7.36	1.53	0.18	13.81	7.54	16.59
-65.9	1.72	0.18	7.42	1.63	0.12	8.80	7.60	4.56
-67.5	1.59	0.26	7.35	2.53	0.57	9.91	10.97	17.56
-68.7	1.59	0.25	7.30	2.41	0.17	9.56	10.43	12.51
-70	1.70	0.25	7.36	2.38	0.28	9.50	11.02	14.32

DH-50-20

DDD

Total Below Surface (ft)	ρb (g/ml)	θg	pH Analysis	NO_3N (ug/g)	NH_4N (ug/g)	Pore Water NO_3N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
-1	1.42	0.25	7.17	5.16	1.11	20.74	19.98	19.98
-2.5	1.51	0.19	7.23	0.93	0.51	5.04	3.85	5.77
-7.5	1.61	0.23	7.74	0.68	0.75	2.98	2.98	7.44
-12.5	1.15	0.22	7.96	1.86	0.57	8.43	5.83	14.57
-15	1.22	0.21	7.91	3.15	0.60	15.02	10.45	26.13
-17.5	1.04	0.23	7.99	3.14	0.40	13.61	8.88	22.21
-20	1.18	0.22	8.01	1.44	0.52	6.45	4.60	11.51
-22.5	1.27	0.22	7.81	3.12	0.00	13.98	10.74	26.85
-25	1.24	0.23	7.85	3.90	0.05	16.73	13.12	32.81
-27.5	1.24	0.25	8.09	2.08	0.00	8.41	7.00	17.50
-30	1.49	0.27	8.15	2.48	0.00	9.15	10.08	25.19
-31	1.24	0.25	8.05	3.74	0.00	15.17	12.64	12.64
-32.5	1.06	0.28	7.91	4.47	0.14	15.97	12.94	19.41
-34	1.09	0.27	7.89	3.24	0.02	12.19	9.61	14.41
-35	1.40	0.25	7.99	2.92	0.24	11.76	11.11	11.11
-37.5	1.20	0.20	7.96	2.73	2.45	13.41	8.90	22.25
-40	1.52	0.20	7.77	1.91	0.37	9.36	7.86	19.66
-42.5	1.32	0.22	8.15	1.32	1.99	6.06	4.75	11.88
-45	1.57	0.24	8.32	1.36	1.11	5.77	5.81	14.52
-47.5	1.24	0.23	8.17	1.93	2.09	8.55	6.52	16.30
-50	1.65	0.22	8.32	2.18	1.67	10.00	9.74	24.36
-52.5	1.40	0.22	8.61	2.83	2.14	12.86	10.79	26.96
-55	1.47	0.22	8.23	3.23	2.91	14.89	12.86	32.15

-57.5	1.41	0.22	8.28	2.59	1.47	12.05	9.92	24.79
-60	1.36	0.21	8.24	2.25	1.96	10.99	8.32	20.81
-62.5	1.37	0.21	8.19	2.02	2.10	9.76	7.52	18.79
-64.5	1.25	0.22	8.33	1.86	1.12	8.39	6.30	12.60
-65	1.71	0.20	8.36	2.09	2.04	10.56	9.74	4.87
-67.5	1.46	0.20	8.08	2.33	1.23	11.55	9.24	23.09
-70	1.24	0.21	8.17	3.69	0.96	17.25	12.45	31.12
-72.5	1.30	0.20	8.11	4.46	1.39	22.66	15.73	39.32
-75	1.52	0.17	8.43	5.00	2.09	29.15	20.64	51.60
-77.5	1.41	0.19	8.12	6.61	1.64	34.87	25.44	63.60
-80	1.75	0.18	8.20	6.24	1.80	34.09	29.72	74.29
-82.5	1.21	0.22	8.07	7.64	1.94	34.46	25.05	62.61
-85	1.48	0.22	8.02	6.01	3.28	27.01	24.22	60.54
-87.5	1.37	0.19	8.18	3.60	1.53	18.98	13.42	33.55
-90	1.31	0.17	8.08	2.93	1.66	17.21	10.45	26.12
-92.5	1.42	0.16	8.00	2.23	3.03	13.76	8.65	21.62
-95	1.58	0.19	8.31	2.39	1.73	12.37	10.25	25.63
-97.5	1.80	0.10	8.38	0.88	2.27	9.29	4.33	10.82
-101.5	1.11	0.21	7.84	1.10	1.21	5.20	3.30	4.95
-104	1.58	0.16	8.04	1.11	0.85	6.82	4.77	11.93
-107.5	1.44	0.16	8.13	1.03	0.72	6.40	4.06	10.15
-112	1.27	0.12	7.97	0.90	0.76	7.48	3.13	6.26
-117.5	1.26	0.14	7.83	0.99	1.05	7.02	3.39	8.48
-120	1.32	0.15	7.84	0.78	1.76	5.26	2.82	7.04
-122.5	1.40	0.22	7.88	1.07	1.20	4.94	4.09	10.23
-125	1.24	0.21	7.84	0.88	1.01	4.16	2.95	7.37

FFF

-125.5	1.18	0.21	7.97	0.99	1.25	4.72	3.17	1.58
-127.5	1.07	0.22	8.07	1.00	1.17	4.45	2.89	5.78
-130	1.08	0.18	8.06	0.72	0.92	4.10	2.11	5.28
-133	1.14	0.16	7.91	0.74	0.86	4.53	2.29	6.87
-137.5	1.07	0.27	8.00	1.21	1.08	4.48	3.53	8.84
-140	1.78	0.18	7.83	0.86	1.91	4.64	4.16	10.40
-142	1.52	0.17	7.92	0.95	1.75	5.52	3.91	7.82
-144	1.81	0.10	8.23	0.54	2.53	5.33	2.68	5.35
-147	1.52	0.08	8.24	0.48	2.06	6.03	1.96	3.92

MSEA-3-17

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-2	1.42	0.23	6.59	5.16	1.60	22.82	19.96	39.93
-3.5	1.40	0.15	6.70	0.77	1.49	4.99	2.93	4.40
-4.5	1.47	0.11	7.03	0.72	0.93	6.46	2.86	2.86
-5	1.27	0.17	6.98	0.23	2.41	1.32	0.78	0.39
-7.5	1.78	0.04	7.13	0.35	0.66	7.99	1.70	4.26
-10	1.75	0.06	7.23	0.63	0.51	10.93	3.02	7.56
-11	1.72	0.05	7.14	0.53	0.71	10.47	2.49	2.49
-12.5	2.02	0.05	7.33	0.63	0.62	12.57	3.46	5.18
-15	2.17	0.04	7.28	0.83	0.46	21.17	4.90	12.26
-17.5	1.97	0.06	7.25	0.30	1.53	5.34	1.62	4.04
-20	1.78	0.15	7.11	2.14	0.53	14.04	10.34	25.85

MSEA-6-17

Total Below Surface (ft)	ρ_b (g/ml)	Θ_g	pH Analysis	NO_3N (ug/g)	NH_4N (ug/g)	Pore Water NO_3N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
-2	1.29	0.25	7.11	2.95	1.85	11.77	10.38	20.76
-4	1.39	0.23	7.20	1.20	1.90	5.17	4.51	6.77
-5	1.62	0.22	7.14	1.54	1.58	7.15	6.80	6.80
-6	1.30	0.25	7.33	2.59	2.22	10.51	9.14	9.14
-7	1.43	0.17	7.56	1.09	0.74	6.34	4.24	4.24
-10	1.57	0.16	7.83	0.55	0.55	3.55	2.36	5.90
-10.3	1.06	0.24	7.47	1.03	2.51	4.29	2.98	0.89
-12.5	1.77	0.10	7.91	0.60	0.57	5.88	2.89	6.37
-15	1.85	0.11	7.81	1.25	0.59	11.43	6.30	15.75
-17.5	1.77	0.12	7.83	0.48	0.75	3.94	2.33	5.83
-20	1.87	0.17	7.89	1.59	0.95	9.45	8.06	20.15

Rosenau-17-19

Total Below Surface (ft)	ρ_b (g/ml)	Θ_g	pH Analysis	NO_3N (ug/g)	NH_4N (ug/g)	Pore Water NO_3N (mg/L)	lbs-N/Acre	lbs-N/Acre in cored interval
-1.5	1.18	0.20	7.60	5.61	1.41	28.56	17.97	26.95
-2.5	1.15	0.21	7.54	2.99	2.30	14.37	9.37	9.37
-3.5	1.20	0.19	7.83	1.95	1.27	10.15	6.36	6.36
-5	1.15	0.18	8.03	1.45	0.91	7.96	4.51	6.77
-7	1.43	0.15	8.03	3.78	0.56	25.67	14.65	29.31
-12.5	1.29	0.16	8.00	1.45	0.74	9.19	5.09	12.71

-15	1.09	0.16	7.94	3.82	0.58	23.72	11.28	28.19
-17	1.62	0.16	8.16	3.61	0.49	22.66	15.88	31.76
-22.5	1.29	0.22	8.06	0.46	0.64	2.11	1.61	4.01
-25	1.39	0.23	7.73	0.52	0.68	2.32	1.98	4.94
-27.5	1.76	0.08	8.32	0.22	0.67	2.84	1.04	2.59
-32	2.07	0.04	8.49	0.05	0.64	1.21	0.28	0.56
-36.5	1.84	0.11	8.43	0.34	1.67	3.18	1.72	2.58
-42	1.63	0.06	8.51	0.19	0.87	3.28	0.82	1.64
-46.5	1.57	0.11	8.49	0.28	1.36	2.45	1.18	1.77
-51	1.23	0.12	8.45	0.48	1.01	3.96	1.62	1.62
-53.3	1.58	0.17	8.36	0.71	1.48	4.12	3.04	6.99
-57.5	1.57	0.17	8.09	0.59	0.66	3.45	2.53	6.32
-62.5	1.42	0.16	7.78	0.80	1.08	4.99	3.09	7.74
-65	1.64	0.19	7.71	1.19	0.70	6.12	5.29	13.23
-66.5	1.51	0.20	7.86	2.30	1.00	11.54	9.47	14.20
-71	1.41	0.20	7.75	7.27	0.88	35.71	27.95	27.95
-72.5	1.33	0.24	7.72	7.20	0.76	30.47	26.01	39.01
-75	1.25	0.22	7.72	7.08	1.23	32.72	24.13	60.33
-77	1.79	0.19	7.84	5.19	1.12	27.67	25.31	50.62
-85	1.26	0.16	7.99	1.19	0.71	7.52	4.10	10.25
-87.5	1.48	0.16	8.26	1.82	0.42	11.56	7.30	18.24
-90	1.51	0.17	8.09	1.83	0.56	11.06	7.52	18.79
-92.5	1.54	0.14	8.21	1.40	0.65	9.80	5.86	14.66
-95	1.70	0.13	8.26	0.96	0.50	7.69	4.46	11.15
-97	1.40	0.06	8.61	0.40	0.63	6.33	1.52	3.04
-98	1.76	0.11	8.56	0.64	0.60	5.71	3.04	3.04

-102	1.00	0.18	8.09	1.23	0.73	6.75	3.34	6.67
-102.5	1.34	0.23	8.11	1.84	0.84	8.04	6.73	3.36
-107	1.52	0.21	8.00	2.00	0.85	9.54	8.25	16.49

RS-1-20

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.21	0.24	5.68	9.48	3.23	38.97	31.08	31.08
-2	1.44	0.18	6.62	5.19	1.65	29.59	20.27	20.27
-7.5	1.25	0.19	7.95	3.50	0.22	18.88	11.93	29.84
-10	1.05	0.21	8.05	3.14	0.00	15.10	8.98	22.45
-12.5	1.21	0.20	8.23	3.18	0.62	16.18	10.49	26.22
-17.5	1.26	0.18	8.19	6.21	0.47	34.24	21.28	53.21
-20	1.02	0.19	8.43	5.70	0.00	29.27	15.85	39.63
-22.5	1.07	0.19	8.00	4.12	0.05	22.19	11.98	29.96
-25	1.20	0.18	8.20	3.00	0.00	16.59	9.74	24.35
-27.5	1.30	0.18	7.84	3.00	0.16	16.25	10.60	26.51
-30	1.38	0.17	8.07	2.59	0.13	14.96	9.73	24.33
-32.5	1.30	0.16	7.97	1.41	0.05	8.91	4.97	12.43
-33.5	1.31	0.11	7.77	0.42	0.05	3.75	1.50	1.50
-34.5	1.37	0.11	8.06	0.42	0.04	4.01	1.58	1.58
-35	1.33	0.16	7.77	2.33	0.77	14.24	8.42	4.21

-37.5	1.30	0.10	7.36	0.36	0.17	3.62	1.28	3.20
-40	1.48	0.09	7.33	0.48	0.28	5.10	1.92	4.79
-41	1.36	0.08	7.49	0.37	0.61	4.43	1.38	1.38
-46	1.40	0.11	7.20	0.34	0.60	3.05	1.29	1.29
-51.5	1.16	0.12	7.22	0.49	1.01	4.26	1.55	2.32
-58	1.26	0.14	7.28	1.99	0.53	14.67	6.84	20.52
-61	1.38	0.14	7.40	0.58	0.74	4.08	2.19	2.19
-64	1.23	0.16	7.63	1.73	0.35	11.18	5.81	17.44
-67	1.09	0.17	7.45	0.79	1.15	4.63	2.33	4.67
-69	1.89	0.14	7.28	0.90	0.96	6.39	4.66	9.31
-72.5	1.52	0.06	7.57	2.43	0.56	43.98	10.05	25.12
-76	1.00	0.33	8.17	1.22	0.88	3.71	3.30	3.30
-78	1.44	0.15	7.97	2.66	0.72	17.91	10.46	20.91
-83	1.35	0.32	8.28	3.09	0.87	9.51	11.37	34.12
-87.5	1.34	0.17	8.16	1.15	0.57	6.55	4.16	10.40
-92	1.70	0.10	8.26	1.21	0.46	12.07	5.60	11.19
-97	1.21	0.24	8.29	1.14	0.76	4.82	3.74	7.49
-98	1.45	0.26	8.49	0.63	0.80	2.40	2.48	2.48
-101.5	1.31	0.27	8.51	0.53	0.24	1.98	1.89	2.84
-102.5	1.54	0.19	8.52	0.86	0.45	4.44	3.61	3.61
-107.5	1.39	0.27	7.96	0.86	0.68	3.14	3.26	8.15
-110	1.91	0.23	8.38	1.78	0.45	7.76	9.27	23.18

RS-6-17

Total Below	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**

KKK

Surface (ft)								
-4	1.31	0.24	7.29	6.94	1.61	29.49	24.64	36.96
-7	1.35	0.17	8.42	2.03	0.75	11.70	7.43	14.85
-8	1.31	0.20	8.28	2.67	0.77	13.13	9.54	9.54
-13.3	1.62	0.20	8.32	1.73	1.42	8.81	7.66	6.13
-17.5	1.11	0.22	8.60	2.66	0.79	11.92	8.04	20.10
-20	1.21	0.22	8.65	2.30	1.17	10.25	7.59	18.98
-24	1.75	0.22	8.68	3.02	1.05	13.89	14.40	21.60
-27.5	1.25	0.27	8.75	4.39	0.73	16.42	14.92	37.31
-28	1.34	0.27	8.53	5.17	0.95	19.49	18.86	9.43
-30	1.41	0.26	8.46	5.72	0.85	21.68	21.85	43.69
-35	1.74	0.20	8.45	4.22	0.92	21.12	19.95	49.87
-37.5	1.55	0.20	8.43	2.92	1.20	14.33	12.32	30.79
-40	1.84	0.23	8.34	4.33	1.65	18.80	21.68	54.20
-40.5	1.53	0.24	8.23	3.71	1.80	15.77	15.40	7.70
-45	1.83	0.17	8.27	2.66	1.30	15.42	13.22	33.05
-47	1.21	0.15	8.06	2.53	1.51	17.07	8.29	16.58
-50	1.47	0.15	8.04	2.73	0.91	18.52	10.90	27.26
-50.5	1.67	0.10	8.02	2.82	1.78	27.14	12.78	6.39
-55	1.65	0.08	7.95	3.78	1.16	45.33	16.93	42.33
-57.5	1.27	0.21	8.06	4.26	1.77	20.30	14.73	36.82
-60	1.79	0.09	8.17	2.23	0.84	25.51	10.89	27.23
-61	1.69	0.07	8.19	0.98	1.65	13.24	4.50	4.50
-63.5	1.94	0.09	8.12	0.78	1.33	8.19	4.11	10.28
-70	2.07	0.11	8.12	1.60	1.76	14.52	8.99	22.48
-75	1.89	0.10	7.93	1.54	1.64	16.09	7.92	19.79

-80	1.57	0.09	7.91	1.95	1.90	22.09	8.31	20.77
-85.5	1.71	0.14	7.84	1.46	2.73	10.28	6.77	13.53
-90	1.62	0.12	8.14	2.54	1.77	21.44	11.19	27.96
-92.5	1.63	0.09	8.23	2.99	3.19	35.10	13.23	6.62
-95	1.83	0.15	8.25	1.82	2.57	12.48	9.01	22.53
-100	1.95	0.12	8.16	3.26	1.14	26.76	17.30	43.26
-105	1.81	0.09	8.33	1.28	1.61	13.66	6.30	12.59
-110	1.66	0.04	8.46	0.79	1.62	18.61	3.55	1.77
-113.3	1.92	0.10	8.32	1.65	1.27	15.91	8.60	6.88
-115	1.59	0.08	8.50	0.93	0.79	12.28	3.99	6.79
-120	1.79	0.06	8.34	0.75	0.97	12.30	3.64	7.28

RS-8-17v

Total Below Surface (ft)	**ρb (g/ml)**	**ϴg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-2	1.41	0.21	6.75	4.28	3.43	20.42	16.37	32.73
-4	1.45	0.24	6.80	0.40	2.40	1.65	1.59	3.18
-9.5	1.49	0.22	7.17	0.85	1.12	3.86	3.44	6.87
-12.5	1.15	0.21	7.23	2.27	1.67	10.81	7.13	17.82
-15	1.05	0.20	7.23	0.67	1.20	3.37	1.92	4.79
-18.5	1.53	0.26	7.25	0.11	1.74	0.43	0.47	0.47
-22.5	1.29	0.25	7.33	1.49	1.10	5.93	5.21	13.04
-25	1.23	0.26	7.37	0.45	1.08	1.75	1.49	3.74
-30	1.46	0.27	7.26	0.54	1.08	2.02	2.16	5.41
-32.5	1.39	0.18	7.06	0.04	1.04	0.25	0.17	0.41

-35	1.28	0.17	7.07	0.09	1.29	0.55	0.32	0.81
-37	1.47	0.22	7.12	0.62	1.71	2.86	2.48	4.97
-40	1.51	0.24	7.80	0.45	3.11	1.88	1.85	4.62
-42.5	1.25	0.24	7.60	0.65	2.21	2.71	2.19	5.48
-45	1.47	0.24	7.54	0.74	0.77	3.12	2.96	7.40
-47.5	1.52	0.25	7.59	0.78	1.03	3.16	3.22	2.25
-50	1.64	0.23	7.50	0.69	1.55	3.03	3.10	7.75
-52.5	1.84	0.23	7.50	0.80	1.26	3.46	3.98	9.96
-55	1.48	0.24	7.50	0.67	1.11	2.78	2.70	6.74
-60	1.52	0.23	7.50	0.72	1.04	3.11	2.99	7.47
-62.5	1.53	0.22	7.58	0.77	1.13	3.60	3.21	8.04
-65	1.30	0.22	7.58	0.91	0.79	4.21	3.23	8.07
-70	1.75	0.23	7.49	1.02	1.06	4.45	4.85	12.13
-72.5	1.46	0.21	7.54	0.48	0.89	2.27	1.89	4.72
-75	1.64	0.21	7.20	0.85	0.65	3.99	3.78	9.44
-77.5	1.75	0.19	7.18	1.11	1.21	5.69	5.28	2.64
-80	1.74	0.21	7.20	0.99	0.90	4.73	4.67	11.68
-82.5	1.21	0.19	7.24	0.05	1.66	0.27	0.17	0.43
-85	1.74	0.22	7.22	0.83	1.13	3.83	3.93	9.83
-87.5	1.60	0.18	7.17	0.69	1.91	3.87	3.02	7.55
-90	1.58	0.22	7.13	0.78	1.37	3.61	3.34	8.34
-92.5	1.38	0.21	7.22	0.33	1.70	1.61	1.25	3.12
-95	1.56	0.21	7.15	0.42	1.46	2.03	1.79	4.48
-97.5	1.57	0.20	7.20	1.15	1.01	5.64	4.90	12.24
-100	1.71	0.21	7.14	1.14	1.15	5.34	5.28	13.20

RS-9-17

Total Below Surface (ft)	**ρb (g/ml)**	**Θg**	**pH Analysis**	**NO_3N (ug/g)**	**NH_4N (ug/g)**	**Pore Water NO_3N (mg/L)**	**lbs-N/Acre**	**lbs-N/Acre in cored interval**
-1	1.26	0.24	6.62	8.86	2.92	37.29	30.33	30.33
-2	1.27	0.20	7.12	2.35	1.54	11.90	8.16	8.16
-7	1.39	0.17	7.33	0.79	1.24	4.59	3.00	6.01
-12.5	1.25	0.18	7.54	1.08	0.67	5.87	3.67	9.17
-15	1.53	0.20	7.58	0.82	0.49	4.17	3.41	8.54
-18.5	1.46	0.19	7.52	0.73	0.96	3.75	2.91	2.91
-22.5	1.33	0.20	7.51	0.98	0.52	4.99	3.55	8.87
-25	1.31	0.19	6.65	0.54	1.03	2.85	1.90	4.75
-30	1.47	0.20	6.84	1.45	0.83	7.38	5.79	14.48
-32.5	1.05	0.21	6.80	2.69	0.36	12.66	7.66	19.16
-35	1.35	0.20	6.63	2.77	0.55	13.90	10.19	25.47
-39.5	1.67	0.17	6.46	3.84	0.72	22.92	17.43	34.86
-45	1.51	0.15	6.42	3.40	1.19	23.32	13.97	34.94
-51	1.31	0.09	6.81	1.94	1.40	21.04	6.92	6.92
-58	1.29	0.10	6.99	2.04	2.19	21.29	7.15	3.57
-64	1.56	0.11	6.87	2.15	0.67	19.78	9.12	13.68
-69	1.26	0.11	6.85	1.65	0.99	15.31	5.65	8.48
-70	1.56	0.23	6.89	9.97	0.43	43.93	42.43	106.07
-73.5	1.32	0.19	6.81	2.16	0.98	11.21	7.78	7.78
-78.5	1.59	0.17	6.72	11.52	0.89	66.60	49.76	49.76
-84.5	1.40	0.19	6.75	48.65	0.72	261.63	185.01	370.02
-90	1.40	0.25	8.01	49.90	1.00	198.06	190.19	475.46
-95	1.39	0.28	8.01	29.09	0.60	103.57	109.55	273.88

-100	1.72	0.13	8.25	14.27	1.06	109.25	66.78	66.78
-105	1.43	0.04	8.51	5.35	1.49	147.88	20.84	31.26
-110	1.28	0.04	8.98	1.55	0.65	38.35	5.41	8.11
-113.5	1.14	0.30	8.35	2.67	1.48	8.77	8.26	8.26
-115	1.44	0.22	8.25	1.40	0.88	6.38	5.50	8.24

Appendix 3: Particle Analysis

DH-19

Total Below Surface (ft)	**% Silt**	**% Sand**	**% Clay**	**Class**
-3.7	45.1%	23.2%	31.7%	Clay Loam
-5	42.9%	34.9%	22.2%	Loam
-7.5	60.4%	26.1%	13.4%	Silt Loam
-9.7	49.1%	36.3%	14.7%	Loam
-12.5	54.5%	30.6%	14.9%	Silt Loam
-15	46.1%	36.7%	17.2%	Loam
-17.5	59.9%	23.4%	16.7%	Silt Loam
-20	57.3%	24.6%	18.1%	Silt Loam
-22.5	49.4%	29.5%	21.1%	Loam
-25	54.7%	26.3%	19.0%	Silt Loam
-27.5	42.9%	35.6%	21.5%	Loam
-29.5	17.4%	71.0%	11.6%	Sandy Loam
-35	8.1%	87.6%	4.3%	Loamy Sand
-40	4.4%	89.4%	6.2%	Loamy Sand
-45	5.6%	86.9%	7.5%	Loamy Sand
-45.4	20.6%	67.0%	12.4%	Sandy Loam
-48	26.0%	56.4%	17.6%	Sandy Loam
-49.5	19.6%	65.8%	14.7%	Sandy Loam
-50	36.9%	43.5%	19.5%	Loam
-52.5	40.6%	36.4%	23.0%	Loam
-55	35.6%	39.8%	24.6%	Loam
-57.5	42.8%	31.4%	25.8%	Loam
-59.4	52.6%	18.6%	28.8%	Silty Clay Loam
-60.7	51.1%	14.9%	34.0%	Silty Clay Loam
-63	18.9%	68.8%	12.3%	Sandy Loam
-65	40.6%	24.4%	35.0%	Clay Loam
-70	6.2%	87.3%	6.5%	Loamy Sand
-75	10.4%	80.1%	9.5%	Loamy Sand
-78	37.3%	41.1%	21.6%	Loam
-80	26.5%	51.8%	21.8%	Loam
-80.5	33.4%	42.9%	23.7%	Loam
-82.5	41.9%	30.4%	27.7%	Loam
-84	21.3%	60.2%	18.5%	Sandy Loam
-85	7.7%	82.2%	10.2%	Sandy Loam
-88.8	24.3%	54.3%	21.4%	Sandy Clay Loam
-90	5.8%	88.5%	5.6%	Lomy Sand

-94	4.3%	92.7%	3.0%	Sand

DH-31

Total Below Surface (ft)	% Silt	% Sand	% Clay	Class
-1	52.0%	25.8%	22.2%	Silt Loam
-4.5	55.4%	18.5%	26.2%	Silt Loam
-5.4	55.1%	22.6%	22.3%	Silt Loam
-12.5	48.1%	37.4%	14.5%	Loam
-17.5	50.0%	35.4%	14.6%	Loam
-23	49.2%	42.6%	8.2%	Loam
-26	55.6%	35.3%	9.1%	Silt Loam
-32.5	62.1%	27.8%	10.1%	Silt Loam
-35	58.9%	31.9%	9.2%	Silt Loam
-37.5	62.4%	25.0%	12.6%	Silt Loam
-40	55.8%	29.5%	14.7%	Silt Loam
-42.5	60.3%	22.4%	17.3%	Silt Loam
-45	45.9%	35.6%	18.5%	Loam
-47.5	42.4%	34.0%	23.6%	Loam
-50	45.3%	26.5%	28.2%	Loam
-52.5	57.7%	21.4%	21.0%	Silt Loam
-54	65.9%	11.5%	22.6%	Silt Loam
-57.5	60.3%	15.0%	24.7%	Silt Loam
-60	51.0%	23.8%	25.2%	SIlt Loam
-62.5	57.9%	19.5%	22.6%	Silt Loam
-65	50.0%	24.8%	25.2%	Loam
-67.5	43.3%	33.0%	23.6%	Loam
-70	24.7%	30.1%	45.1%	Clay
-72	37.0%	38.1%	24.9%	Clay Loam
-73.5	35.0%	41.1%	23.9%	Loam
-75	43.6%	31.9%	24.5%	Loam
-77	49.8%	23.0%	27.3%	Loam
-79	49.3%	19.5%	31.2%	Clay Loam
-80.5	56.6%	15.0%	28.3%	Silty Clay Loam
-82.5	50.1%	21.0%	28.9%	Silt Loam
-84	54.4%	14.8%	30.8%	Silty Clay Loam
-85	47.2%	16.8%	36.0%	Silty Clay Loam
-88	44.0%	24.1%	31.8%	Clay Loam
-90	42.3%	29.0%	28.7%	Clay Loam
-92.5	34.2%	34.2%	31.6%	Clay Loam
-94	36.5%	33.0%	30.5%	Clay Loam
-95	42.5%	29.4%	28.1%	Loam

-97	42.4%	26.8%	30.8%	Clay Loam
-99	37.4%	31.6%	31.0%	Clay Loam
-101	40.8%	31.4%	27.8%	Loam
-102.5	46.3%	31.6%	22.2%	Loam
-104	55.4%	20.1%	24.5%	Silt Loam
-105	47.4%	22.1%	30.5%	Loam
-107.5	43.9%	24.4%	31.7%	Clay Loam
-109	19.7%	57.8%	22.6%	Sandy Clay Loam
-110	40.2%	34.3%	25.5%	Loam

DH-32

Total Below Surface (ft)	**% Silt**	**% Sand**	**% Clay**	**Class**
-5	55.4%	10.4%	34.2%	Silty Clay Loam
-8	64.7%	21.2%	14.1%	Silt Loam
-10	63.0%	22.4%	14.6%	Silt Loam
-15	67.2%	18.3%	14.5%	Silt Loam
-17.5	70.2%	17.3%	12.5%	Silt Loam
-20	71.0%	15.7%	13.3%	Silt Loam
-23.6	61.6%	19.7%	18.6%	Silt Loam
-25	62.6%	17.7%	19.7%	Silt Loam
-27.1	48.7%	24.7%	26.6%	Loam
-28.6	30.5%	47.4%	22.1%	Loam
-30	20.9%	61.0%	18.2%	Sandy Loam
-32.2	20.9%	61.3%	17.8%	Sandy Loam
-32.9	10.5%	76.4%	13.1%	Sandy Loam
-33.8	17.3%	67.5%	15.2%	Sandy Loam
-35	5.7%	87.4%	6.9%	Loamy Sand
-40	4.2%	89.5%	6.3%	Loamy Sand
-43.7	23.4%	65.1%	11.5%	Sandy Loam
-45	24.8%	61.3%	13.8%	Sandy Loam
-49	15.4%	72.8%	11.8%	Sandy Loam
-50	20.3%	67.7%	12.0%	Sandy Loam
-55	7.3%	83.1%	9.6%	Loamy Sand
-59.3	10.9%	79.8%	9.3%	Sandy Loam
-60	18.2%	70.7%	11.1%	Sandy Loam
-63	19.9%	64.7%	15.4%	Sandy Loam
-63.2	33.2%	39.0%	27.8%	Clay Loam
-65	9.2%	84.1%	6.7%	Loamy Sand
-70	4.3%	93.8%	1.9%	Sand
-75	8.5%	84.3%	7.3%	Loamy Sand
-80	10.9%	81.1%	8.1%	Loamy Sand

-85	5.4%	89.9%	4.7%	Loamy Sand

DH-37

Total Below Surface (ft)	% Silt	% Sand	% Clay	Class
-1	40.2%	40.1%	19.6%	Loam
-6.5	47.0%	36.4%	16.7%	Loam
-7.5	61.4%	9.2%	29.4%	Silty Clay Loam
-11.3	44.5%	32.8%	22.7%	Loam
-17.5	50.3%	38.1%	11.6%	Silt Loam
-19	37.3%	51.0%	11.7%	Loam
-20.5	51.5%	36.6%	11.9%	Silt Loam
-21.3	60.1%	22.1%	17.7%	Silt Loam
-27	51.5%	37.0%	11.5%	Silt Loam
-29	48.2%	40.6%	11.2%	Loam
-30	72.7%	9.3%	18.0%	Silt Loam
-31.8	60.4%	16.2%	23.4%	Silt Loam
-37.5	54.2%	25.3%	20.6%	Silt Loam
-40	50.1%	32.2%	17.7%	Silt Loam
-45	45.6%	30.2%	24.2%	Loam
-47.5	46.5%	37.3%	16.2%	Loam
-50	53.0%	33.2%	13.8%	Silt Loam

DH-40

Total Below Surface (ft)	% Silt	% Sand	% Clay	Class
-1	30.7%	54.0%	15.2%	Sandy Loam
-2	23.2%	49.1%	27.7%	Sandy Clay Loam
-3	30.0%	51.1%	18.9%	Loam
-3.8	24.3%	52.1%	23.6%	Sandy Clay Loam
-12	23.8%	64.5%	11.7%	Sandy Loam
-16.5	27.9%	50.0%	22.2%	Loam
-17	35.8%	51.7%	12.5%	Loam
-22.5	37.7%	50.5%	11.8%	Loam
-25	35.9%	53.3%	10.8%	Sandy Loam
-27.3	34.0%	54.3%	11.7%	Sandy Loam
-31.9	44.3%	42.7%	13.0%	Loam
-47.5	32.6%	54.3%	13.0%	Sandy Loam
-50	36.4%	52.0%	11.6%	Sandy Loam
-37.5	39.9%	46.9%	13.2%	Loam
-40	34.6%	54.0%	11.4%	Sandy Loam
-42	45.0%	41.3%	13.7%	Loam

-52.5	31.7%	54.8%	13.5%	Sandy Loam
-55	32.6%	52.9%	14.5%	Loam
-56.8	23.3%	64.9%	11.8%	Sandy Loam
-61	21.3%	68.1%	10.7%	Sandy Loam
-62.1	9.9%	82.5%	7.6%	Loamy Sand
-66.3	23.0%	65.9%	11.1%	Sandy Loam
-67.3	28.4%	60.2%	11.4%	Sandy Loam
-73	32.6%	58.7%	8.7%	Sandy Loam
-77	39.7%	50.0%	10.3%	Loam
-78	46.8%	42.8%	10.4%	Loam

DH-47

Total Below Surface (ft)	**% Silt**	**% Sand**	**% Clay**	**Class**
-3.7	55.4%	22.9%	21.7%	Silt Loam
-5	45.1%	25.2%	29.8%	Clay Loam
-8.8	60.2%	25.6%	14.2%	Silt Loam
-10	63.3%	19.8%	16.9%	Silt Loam
-12.5	69.5%	19.9%	10.6%	Silt Loam
-15	64.3%	22.8%	13.0%	Silt Loam
-18	44.3%	45.5%	10.2%	Loam
-20	54.2%	34.5%	11.3%	Silt Loam
-21.5	65.7%	20.9%	13.3%	Silt Loam
-23.5	42.3%	29.1%	28.7%	Clay Loam
-25	35.4%	39.0%	25.7%	Clay Loam
-28	25.6%	51.4%	23.0%	Sandy Clay Loam
-30	10.3%	78.5%	11.2%	Sandy Loam
-35	7.2%	83.0%	9.8%	Loamy Sand
-39.2	8.0%	82.3%	9.7%	Loamy Sand
-40	19.6%	63.9%	16.5%	Sandy Loam
-43.7	16.8%	70.7%	12.6%	Sandy Loam
-45	40.2%	39.9%	19.9%	Loam
-48.7	39.3%	34.4%	26.4%	Loam
-50	32.1%	46.2%	21.6%	Loam
-53.6	15.2%	72.1%	12.7%	Sandy Loam
-55	32.9%	46.6%	20.6%	Loam
-57.7	32.7%	50.6%	16.7%	Loam
-59	35.4%	46.4%	18.3%	Loam
-60	21.3%	63.1%	15.6%	Sandy Loam
-62.5	8.8%	80.6%	10.6%	Sandy Loam
-64	10.5%	79.7%	9.9%	Sandy Loam
-65.4	19.2%	65.7%	15.1%	Sandy Loam

-66.2	17.2%	67.0%	15.8%	Sandy Loam
-67.5	12.6%	73.2%	14.3%	Sandy Loam
-69.5	33.0%	47.2%	19.7%	Loam
-70.5	13.5%	76.7%	9.8%	Sandy Loam
-72.5	8.6%	84.8%	6.6%	Loamy Sand
-80	4.9%	90.5%	4.6%	Sand
-85	5.8%	87.4%	6.8%	Loamy Sand

DH-48

Total Below Surface (ft)	**% Silt**	**% Sand**	**% Clay**	**Class**
-1.5	45.7%	22.4%	31.9%	Clay Loam
-3	44.3%	16.2%	39.5%	Silty Clay
-4	43.6%	30.2%	26.2%	Loam
-5	49.6%	32.3%	18.1%	Loam
-7	45.7%	41.2%	13.1%	Loam
-10	52.6%	33.3%	14.1%	Silt Loam
-15	50.7%	34.4%	14.9%	Silt Loam
-17.5	58.9%	27.2%	13.9%	Silt Loam
-20	47.5%	36.3%	16.2%	Loam
-22.5	59.1%	19.6%	21.3%	Silt Loam
-23.8	51.7%	29.9%	18.4%	Silt Loam
-26.3	28.6%	42.3%	29.1%	Clay Loam
-27.5	23.9%	53.8%	22.3%	Sandy Clay Loam
-30	17.3%	66.2%	16.5%	Sandy Loam
-32.5	15.4%	69.0%	15.6%	Sandy Loam
-35	29.5%	55.8%	14.7%	Sandy Loam
-35	9.7%	79.7%	10.6%	Sandy Loam
-40	34.9%	40.1%	25.0%	Loam
-42.5	38.3%	41.5%	20.2%	Loam
-44.3	18.8%	70.1%	11.1%	Sandy Loam
-45	28.1%	57.6%	14.3%	Sandy Loam
-50	15.5%	72.7%	11.8%	Sandy Loam
-55	16.7%	78.9%	4.3%	Loamy Sand
-60	13.0%	80.6%	6.4%	Loamy Sand
-64	15.2%	69.0%	15.8%	Sandy Loam
-65	19.5%	63.8%	16.7%	Sandy Loam
-66.7	24.2%	50.0%	25.8%	Sandy Clay Loam
-67.5	36.5%	51.7%	11.8%	Loam
-69	30.8%	52.8%	16.4%	Loam
-70	20.0%	67.5%	12.6%	Sandy Loam
-73	13.4%	78.1%	8.5%	Sandy Loam

-75	15.9%	77.0%	7.1%	Sandy Loam

DH-49

Total Below Surface (ft)	**% Silt**	**% Sand**	**% Clay**	**Class**
-0.9	53.7%	25.5%	20.8%	Silt Loam
-1.8	59.5%	18.1%	22.4%	Silt Loam
-7.5	52.0%	25.2%	22.8%	Silt Loam
-10	56.3%	26.3%	17.3%	Silt Loam
-13.9	59.9%	16.9%	23.2%	Silt Loam
-15	68.1%	13.1%	18.8%	Silt Loam
-18.7	66.3%	18.2%	15.5%	Silt Loam
-20	66.5%	15.9%	17.5%	Silt Loam
-25	57.2%	26.1%	16.7%	Silt Loam
-28	37.8%	38.5%	23.7%	Loam
-30	24.2%	50.5%	25.2%	Sandy Clay Loam
-32.6	29.9%	49.7%	20.4%	Loam
-35	24.0%	57.8%	18.2%	Sandy Loam
-37.5	24.3%	60.0%	15.7%	Sandy Loam
-38.5	20.1%	68.0%	11.9%	Sandy Loam
-40	39.8%	35.9%	24.3%	Loam
-42.5	34.2%	46.9%	18.9%	Loam
-45	38.7%	42.6%	18.7%	Loam
-48	20.4%	64.4%	15.2%	Sandy Loam
-50	6.3%	87.8%	5.9%	Loamy Sand
-55	6.8%	86.3%	6.9%	Loamy Sand
-60	4.6%	90.1%	5.4%	Sand
-65	16.5%	72.7%	10.9%	Sandy Loam
-65.9	18.7%	73.5%	7.8%	Sandy Loam
-67.5	48.2%	34.8%	17.0%	Loam
-68.7	32.3%	50.1%	17.6%	Loam
-70	30.0%	57.6%	12.4%	Sandy Loam

Appendix 4: Tabulated TKN, HWEOC, TOC, C:N (liquid and solid), and HWEOC:TOC

DH-32

Depth	**TKN (μg/g)**	**HWEOC (μg/g)**	**TOC (μg/g)**	**δ13C (‰)**	**C:N**	**C:N**	**HWEOC:TOC**
Phase	Liquid	Liquid	Solid	Solid	Solid	Liquid	
-5	1,396	152.3	8,330	-18.0	2.45	0.11	0.02
-10	337	56.0	1,470	-30.8	10.55	0.17	0.04
-15	395	59.8	1,200	-31.6	21.52	0.15	0.05
-17.5	242	61.9	1,260	-31.7	26.36	0.26	0.05
-20	297	55.6	1,000	-32.0	30.45	0.19	0.06
-23.6	215	90.9	1,150	-32.4	14.88	0.42	0.08
-25	208	95.3	1,300	-31.8	17.56	0.46	0.07
-27.1	588	179.0	3,470	-27.9	14.06	0.30	0.05
-28.6	526	159.4	3,910	-25.1	12.69	0.30	0.04
-30	265	106.6	3,210	-29.9	25.85	0.40	0.03
-32.2	187	99.8	1,680	-27.7	22.85	0.53	0.06
-32.9	157	69.4	730	-28.6	29.00	0.44	0.10
-33.8	239	85.1	1,450	-27.0	12.12	0.36	0.06
-35	68	46.6	390	-28.8	29.66	0.69	0.12
-40	52	42.6	340	-25.7	29.80	0.81	0.13
-43.7	124	41.6	670	-31.0	32.80	0.34	0.06
-45	135	46.5	490	-28.3	22.81	0.34	0.09
-49	60	42.7	360	-28.9	23.62	0.72	0.12
-50	94	51.8	370	-24.1	23.13	0.55	0.14
-55	78	43.9	2,530	-27.1	31.06	0.56	0.02
-59.3	74	39.1	300	-34.6	51.18	0.53	0.13
-60	122	51.5	510	-30.4	27.32	0.42	0.10
-63	136	52.7	650	-30.9	19.23	0.39	0.08
-63.2	690	102.3	5,270	-22.2	4.88	0.15	0.02
-65	70	42.5	390	-31.7	31.96	0.60	0.11
-70	41	31.2	220	-32.6	43.71	0.76	0.14
-75	62	36.5	380	-32.1	22.16	0.59	0.10
-80	87	35.6	340	-31.7	26.25	0.41	0.10
min	**41**	**31.2**	**220**	**-34.6**	**2.45**	**0.11**	**0.02**
max	**1,396**	**179.0**	**8,330**	**-18.0**	**51.18**	**0.81**	**0.14**
average	**248**	**70.7**	**1,549**	**-29.1**	**23.57**	**0.43**	**0.08**

DH-36

Depth	**TKN (µg/g)**	**HWEOC (µg/g)**	**TOC (µg/g)**	**δ13C (‰)**	**C:N**	**C:N**	**HWEOC:TOC**
Phase	Solid	Liquid	Solid	Solid	Solid	Liquid	
-1	5.56	254.8	17,500	-17.2	2.32	0.33	0.01
-2	1.45	159.4	11,000	-10.8	2.77	0.26	0.01
-10	0.47	43.9	1,040	-21.9	11.44	0.26	0.04
-12.5	0.67	43.0	1,010	-26.5	27.34	0.37	0.04
-17	2.02	40.1	1,100	-24.0	11.58	2.17	0.04
-19	1.96	42.2	1,000	-23.1	11.48	1.15	0.04
-20	1.33	43.9	950	-23.1	16.68	1.89	0.05
-22.5	1.39	43.7	1,290	-30.6	21.23	0.25	0.03
-25	0.93	42.7	850	-25.1	25.54	0.24	0.05
-26	1.95	45.0	980	-23.4	11.42	0.26	0.05
-28	2.25	44.3	990	-24.6	9.53	0.28	0.04
-30	1.88	43.4	790	-29.9	15.02	0.45	0.05
-32.5	2.81	38.2	890	-32.0	8.08	0.17	0.04
-34	2.67	42.2	800	-26.7	5.13	0.19	0.05
-35.2	0.44	54.3	1,650	-29.3	10.92	0.17	0.03
-36.5	0.26	204.6	25,600	-27.4	3.14	0.16	0.01
-39	0.57	325.8	48,200	-29.0	3.72	0.11	0.01
-41	3.74	74.6	3,990	-20.7	4.17	0.17	0.02
-43.8	4.96	54.1	2,800	-20.3	3.54	0.16	0.02
-45	4.25	40.0	1,340	-21.8	4.84	0.22	0.03
-47.5	5.59	35.4	1,190	-23.2	4.12	0.20	0.03
-49.5	3.92	36.7	740	-23.8	5.99	0.37	0.05
-50.5	2.39	31.8	670	-24.4	5.95	0.48	0.05
-52.5	2.95	31.6	620	-26.0	8.63	0.35	0.05
-56	3.53	31.8	970	-22.9	6.43	0.16	0.03
-57.5	3.85	43.9	1,950	-18.2	4.26	0.19	0.02
-60	3.13	38.7	1,450	-19.3	5.35	0.18	0.03
-62.5	1.53	26.8	550	-28.1	14.68	0.41	0.05
-67.5	5.85	29.2	1,240	-21.2	3.37	0.18	0.02
-69	6.03	28.1	950	-22.0	3.28	0.16	0.03
-70	4.59	30.7	1,170	-21.5	4.43	0.18	0.03
-72.5	5.50	34.7	1,370	-23.3	4.11	0.23	0.03
-74	5.08	49.8	900	-30.4	5.89	0.27	0.06
-75	4.79	27.7	500	-30.7	5.32	0.37	0.06

-77.5	1.99	27.9	300	-27.8	13.65	1.36	0.09
-82.5	3.01	26.6	550	-28.0	9.14	1.17	0.05
-87.5	3.14	27.7	370	-28.9	9.05	0.94	0.07
-91	2.84	26.7	230	-25.7	8.03	1.67	0.12
-92.5	2.27	21.7	220	-26.6	11.46	1.19	0.10
-96.5	7.08	28.3	540	-29.7	4.01	0.37	0.05
-97.5	4.10	28.5	980	-31.4	6.95	0.18	0.03
-102	1.17	27.1	320	-27.2	22.37	2.25	0.08
-106	0.77	31.9	250	-26.6	19.32	2.56	0.13
-107.5	0.91	23.2	280	-26.4	27.46	5.05	0.08
-112.5	0.89	28.5	230	-27.7	29.39	1.28	0.12
-117.5	0.61	28.6	220	-23.2	35.37	5.03	0.13
-122.5	0.58	27.3	270	-29.3	46.69	14.74	0.10
min	**0.26**	**21.7**	**220**	**-32.0**	**2.32**	**0.11**	**0.01**
max	**7.08**	**325.8**	**48,200**	**-10.8**	**46.69**	**14.74**	**0.13**
average	**2.76**	**53.4**	**3,038**	**-25.1**	**11.37**	**1.08**	**0.05**